# HIGHWAY RESEARCH REPORT

# EVALUATION OF THE LANE-WELLS DYNAFLECT

## FINAL REPORT

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**STATE OF CALIFORNIA**

**TRANSPORTATION AGENCY**

**DEPARTMENT OF PUBLIC WORKS**

**DIVISION OF HIGHWAYS**

**MATERIALS AND RESEARCH DEPARTMENT**



**RESEARCH REPORT**

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY
RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
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Final Report
M & R No. 633297
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Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

EVALUATION OF THE

LANE-WELLS DYNAFLECT

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Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Zube, E., Tueller, D. O., Forsyth, R. A. and Hannon, J. B., "Evaluation of the Lane-Wells Dynaflect", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633297, October, 1968.

ABSTRACT: An evaluation of the Lane-Wells Dynaflect is reported. Various correlation and repeatability tests are discussed and compared for this dynamic deflection measuring device and the California Traveling Deflectometer and Standard Benkelman beam. The Dynaflect was used with success on operational pavement deflection investigational work for recommending overlay reconstruction. Various other uses are also reported for flexible and rigid pavements and for surfaced and unsurfaced roadways. Charts showing the maximum critical slope of Dynaflect deflected pavement basins are presented for flexible and cement treated bases. It was concluded that the Dynaflect is a rapid economical means of obtaining pavement deflection measurements and can be used as a reliable tool on pavement deflection investigational studies for recommending reconstruction or corrective maintenance treatment.

KEY WORDS: Pavements, deflection, testing equipment, evaluation, measurements, overlay reconstruction

[illegible] R. A. and [illegible]

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[illegible] and the flexible [illegible] and cement [illegible] concluded that the Dynaflect [illegible] of existing pavement [illegible] and can be used as a reliable [illegible] investigational tool [illegible] corrective action [illegible]

[illegible] deflection, testing equipment, evaluation, [illegible] construction

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This is the final report of a research project to evaluate the Lane-Wells Dynaflect which is a device for the deflection testing of pavements under dynamic oscillatory load. This work was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads (Federal Program No. HPR-1(4), D0464). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads. This report does not constitute an official indorsement or approval of the use of this equipment.

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## INTRODUCTION

The California Division of Highways has long recognized the importance of pavement deflections, having made measurements as early as 1938 with permanently installed gage units. This was expensive and only a few readings could be taken per day. In 1955, as the result of a state-wide deflection study involving nearly 400 electronic gage units on 43 different projects, maximum safe levels of transient deflection were assigned for various types of structural section. These criteria, which are presented below, have been utilized by the California Division of Highways since 1955 for planning the reconstruction of existing highways.[1]

Maximum Tolerable Deflection Levels

| Thickness of Pavement | Type of Pavement | Maximum Permissible Deflection for Design Purposes |
|---|---|---|
| 8-in. | Portland Cement Concrete | 0.012-in. |
| 6-in. | Cement Treated Base (Surfaced with Bituminous Pavement) | 0.012-in. |
| 4-in. | Asphalt Concrete | 0.017-in. |
| 3-in. | Plant Mix on Gravel Base | 0.020-in. |
| 2-in. | Plant Mix on Gravel Base | 0.025-in. |
| 1-in. | Road Mix on Gravel Base | 0.036-in. |
| 1/2-in. | Surface Treatment | 0.050-in. |

The development of the Benkelman beam in 1953 (Figure 1) greatly simplified the measurement of pavement deflections by eliminating the need for permanently installed gage units. However, the procedure was found to be quite time consuming when used over long stretches of highway. This led to the development by the Materials and Research Department, of the California traveling deflectometer (Figure 2) which further simplified this task. The traveling deflectometer provides a rapid means of accumulating a considerable volume of data. However, it and the Benkelman beam device both have the disadvantages of lack of mobility and inability to obtain consistent deflection measurements over unpaved surfaces.

A device that has considerable mobility, but presents a different approach to the measurement of pavement deflection, is called the "Dynaflect".[2] This device on which an evaluation was made, was developed in 1965 by the Lane-Wells Highway Products Company of Houston, Texas. It is a small, self-contained trailermounted, electro-mechanical apparatus (Figure 3) which can be towed behind a passenger vehicle and operated by the driver from inside the tow vehicle. In October, 1966, the Materials and Research Department of the California Division of Highways began the evaluation of this device under a two year cooperative research study with the U. S. Department of Transportation, Bureau of Public Roads.

The device was first demonstrated to the California Division of Highways in the fall of 1965, and the resulting Dynaflect data was compared to that obtained with the traveling deflectometer over several roadways. A reasonably good correlation was found to exist although insufficient information was obtained to warrant a definite conclusion. The Dynaflect did appear to have various potential uses. Because of the relatively light loadings involved, it could possibly be used to obtain deflection measurements on unsurfaced roadbeds during various stages of construction. This has not been possible with the traveling deflectometer or the Benkelman beam due to distortion and up-thrust between the loaded dual wheels of the test vehicle. The Dynaflect also presented the possibility of locating weak spots on subgrades on going construction projects for corrective treatment prior to completion of the structural section. Its greatest potential would be for obtaining deflection measurements on distressed roadways for the purpose of determining necessary overlay repairs or maintenance treatments. Although the Dynaflect is not capable of producing the large volume of data developed by the traveling deflectometer, it does appear to have important advantages of mobility as well as the capability for use on prepared subgrades, subbases and base courses. Because of the many possible uses for this equipment, the Materials and Research Department undertook this Dynaflect evaluation program.

The first phase of this evaluation involved a familiarization program to determine its capabilities. This involved preliminary Benkelman beam correlation studies and repeatability measurements which for the Dynaflect, were found to be excellent. The second phase involved various other correlation studies to determine how well deflection measurements obtained with the Dynaflect correlated to those made by the Benkelman beam and traveling deflectometer. A considerable amount of data has also been collected on shape and slope of deflected basins. This appears to be a good approach to the evaluation of cement treated bases to determine an indication of slab strength.

This study has proven that the Dynaflect is an acceptable deflection measuring device for use in deflection investigational studies.

## CONCLUSIONS

The following conclusions are drawn from the results of this study:

1. Dynaflect deflection measurements generally correlate well with deflection measurements obtained by the standard manually operated Benkelman beam and the California traveling deflectometer.

2. The Dynaflect can reproduce a deflection measurement to a higher accuracy than either the standard manually operated Benkelman beam or the California traveling deflectometer.

3. The Dynaflect provides a rapid economical means of obtaining pavement deflection measurements and can be used as a reliable tool on pavement deflection investigational studies for recommending reconstruction or corrective maintenance treatment. However, the Dynaflect generally produces an overlay design which is more conservative than present deflection measuring equipment.

4. For most pavement deflection investigational work, it is necessary to read only the No. 1 geophone sensor directly under the load rather than the complete geophone array.

5. The slab strength of various roadway structural sections can be compared from the slope of the deflection basin produced by Dynaflect loading.

6. The maximum critical slope of a deflected basin produced by Dynaflect loading was found to be about 0.002 percent for cement treated bases surfaced with asphaltic concrete and about 0.005 percent for an asphaltic concrete surfacing over a flexible base. Cracking of the surfacing within the design life of the facility, can be expected to occur with Dynaflect deflected basin slopes steeper than the above mentioned.

7. A relationship was found to exist between maximum slope of the Dynaflect deflected basin and the maximum tangential slope of the deflection trace produced by the California traveling deflectometer. However, no maximum critical values could be determined for the slope of the deflectometer deflection trace.

8. The Dynaflect can be used to obtain deflection measurements on unsurfaced roadways.

9. The Dynaflect appears promising for use in detecting changes in deflection level due to changes in soil compaction and moisture content. Data indicates that soil moisture content is the most important variable. However, additional study is necessary.

10. Only one location was tested but indicated poor results in determining subgrade modulus K from Dynaflect measurements on PCC pavement surface utilizing Westergaard Analysis.

11. The Dynaflect is capable of determining load transfer across transverse joints in PCC pavement.

12. The Dynaflect appears to be capable of detecting changes in deflection level due to seasonal variations.

## EQUIPMENT

### California Traveling Deflectometer

The deflectometer (Figure 2) is based on the Benkelman beam principle, utilizing one beam in each wheel track. It combines a truck-trailer unit with the two beam probes for simultaneous automatic deflection measurements under both sets of dual wheels. The device is electro-mechanical and is capable of measuring pavement deflections at intervals greater than 12-1/2 foot longitudinally in the wheel tracks while traveling steadily at 1/2 mile per hour. The measured deflections are recorded on a continuous trace to the nearest 0.001 inch. The deflectometer carries a 15,000 pound single axle load. A crew of three men is required. It is capable of obtaining up to 1300 individual deflection measurements per day as opposed to about 300 measurements using the manually operated Benkelman beam.

### Lane-Wells Dynaflect

The "Dynaflect" (Figure 3) is a dynamic force generator and deflection measuring system. A pair of unbalanced flywheels are counter rotated at eight cycles per second and a set of five motion sensing devices and a motion measuring instrument is used to measure the resulting deflection. A tow vehicle with a 12 volt electrical system is utilized to make the unit operational. By means of a hydraulic system, the trailer is lifted from the pavement surface and a pair of steel test wheels, spaced 20 inches apart, are brought down into contact with the pavement to support the trailer unit and transmit the load (Figure 4). Utilizing the static weight of the trailer, which is 1,600 pounds, and the dynamic force generator, a 1,000 pound peak to peak eight cycles per second oscillatory load is transmitted onto the pavement surface by means of the steel test wheels. The actual load on the surface varies from 1100 to 2100 pounds. The resultant amplitude of motion is sensed by a set of five geophones which are also brought into contact with the pavement. They are located along the tongue of the trailer at one foot intervals ahead of the center of loading. With the trailer stopped, resulting amplitudes of vibration produced by the oscillatory loading are read as deflection measurements by means of a deflection measuring meter on the control box (Figure 5) located in the tow vehicle. It is possible to read Dynaflect deflections as high as 30 thousandths of an inch (equivalent to about 600 thousandths of an inch in terms of Benkelman beam deflection) and as low as one hundred thousandth of an inch (Benkelman beam deflection of zero). It is not only possible to measure the maximum deflection under the loading but also the shape of the deflected basin which is produced.

With the geophones raised, the trailer may be moved short distances between readings at slow speed on the steel test wheels. However, at highway speeds these steel test wheels must be raised and the pneumatic trailer wheels lowered.

## EVALUATION PROGRAM

It was proposed to accomplish this study in two phases. Phase I was to consist of equipment familiarization, deflection repeatability measurements and preliminary correlation work involving Dynaflect, Benkelman beam and traveling deflectometer. Phase II was to involve data collection on the deflection damping characteristics of various elements of the structural section and determination of seasonal variations in deflection level by Dynaflect measurement. Various other field experiments and correlation studies were also to be performed. The work plan for Phase II would be contingent upon the results of Phase I. The actual work that was accomplished is presented in the following discussion:

### Phase I

This phase of the evaluation involved the lease of a Dynaflect unit from the Lane-Wells Company through a lease-purchase agreement.

The Dynaflect was delivered to the Materials and Research Department on October 9, 1966 and on April 19, 1967, after a few months of favorable performance, the purchase option was executed.

During this phase of the study, a familiarization program was conducted to determine the capabilities and possible applications of the Dynaflect.

## Correlation to Benkelman Beam

In comparing pavement deflections obtained with the Dynaflect to those obtained with the Benkelman beam under a 15,000 pound single axle load, a curve of best fit was determined by regression analysis and is shown on Figure 6. This work represents a total of 340 different test measurements over 38 test sections using the Dynaflect in conjunction with the manually operated Benkelman beam at the same test locations. The mean deflection levels obtained on these sections produced a coefficient of correlation of 0.98 and a standard error of ± 0.003" to ± 0.005" in terms of Benkelman beam deflection. This preliminary correlation suggests that the Dynaflect is an acceptable deflection measuring tool. However, this data was obtained over a limited number of roadways, and additional information was necessary to make a firm conclusion. Further study revealed that the relationship of Dynaflect deflections to those obtained with either Benkelman beam or traveling deflectometer is linear rather than logarithmic. Work done by other agencies also suggests a linear correlation.[2,3,4]

## Reproducibility of Deflection Measurements

Tests for repeatability of both the Dynaflect and Benkelman beam were also conducted during the first four months of this evaluation study. This was accomplished by comparing the first and second deflection readings over the same points through a wide range of pavement deflection. The results produced a standard error for both Benkelman beam and Dynaflect deflection repeatability of approximately ± 0.004 inch in terms of Benkelman beam deflection. Here, however, the coefficient of correlation for the Benkelman beam was somewhat better at 0.995 as compared to 0.979 for the Dynaflect. It was discovered later that the two unbalanced force wheels of the force generator may have been out of phase during some of the Dynaflect repeatability testing. This was due to faulty factory assembly which was soon remedied by minor modifications. Repeatability tests were again performed with the Dynaflect and the standard error of deflection repeatability was reduced to 0.002 inch in terms of Benkelman beam deflection and the coefficient of correlation was 0.996 (Figure 7). This can now be compared with Benkelman beam results in Figure 8. Repeatability tests were also made with the traveling deflectometer over the same test areas and on the same day as the Dynaflect recheck measurements. This produced a standard error of deflection measurement of 0.005 inch for the deflectometer and a coefficient of correlation of 0.976 (Figure 9). The larger deviation of the repeatability results with the deflectometer is explained by the fact that this device is difficult to maneuver and obtain duplicate measurements over the same exact points. This is confirmed by some of the data scatter in the higher ranges of deflection (above 0.040 inches). A certain amount of this variation can also in part be explained by some surface distortion and up-thrust between the dual tires of the test vehicle during deflection measurement. This is also characteristic of the Benkelman beam test vehicle and, therefore, suggests the advantages of the Dynaflect principle. However, the integrity of the surface is important in transmitting the vibratory loading.

Dynaflect Use on Unsurfaced Roadbed

The Dynaflect's potential use for determining deflection measurements on unsurfaced roadways was first evaluated during Phase I of this study on the Ball Test Road near Concord, California in Contra Costa County. This road was built as an experimental test facility for State Research Project EA643298 "Influence of Subgrade Characteristics on Transient Deflection of AC Pavements". It consisted of six test sections, each 125 feet in length with varying moisture contents and compacted by either pneumatic roller or sheeps foot roller.

Deflection measurements were obtained over this facility with the Lane-Wells Dynaflect following the placement of each layer or increment of the structural section. The resulting deflection attenuation profiles are shown on Figure 10. The near parallel nature of each individual deflection profile shows a high degree of consistency, as well as the degree of deflection attenuation provided by the placement of each structural section layer.

During the second phase of this evaluation, other deflection applications on unsurfaced roadbeds were performed and will be explained in the section of this report which deals with Phase II.

## Cement Treated Base Evaluation

Further evaluation during Phase I consisted of the first operational application of the Dynaflect unit on Kifer Road in the City of Sunnyvale, California.

The facility is a four-lane roadway which was still under construction at the time of deflection testing. The proposed structural section consisted of 0.33 foot of asphaltic concrete over 0.50 foot of cement treated base. This study was made over the asphaltic concrete leveling course on which an additional 0.17 foot of asphaltic concrete was still to be placed.

In the progress of control testing, samples of cement treated base from one area of this roadway exhibited compressive strengths below the minimum specification requirement of 750 psi. Whereas, samples taken from other portions of the facility were found to be well above this minimum specification requirement. As the result of these compressive strength tests, all paving operations were halted after the completion of the leveling course. This department was then requested to evaluate the existing nearly constructed roadway based on pavement deflection criteria. The principle objective of this investigation was to obtain an indication of the in-place strength of the newly placed cement treated base and possibly delineate any weak or substandard areas for corrective treatment prior to the placement of the final 0.17 foot asphaltic concrete surface course.

Dynaflect deflection measurements were generally obtained at 0.01 mile intervals throughout the project. These measurements were made over the 0.17 foot asphaltic concrete leveling course and were converted to standard Benkelman beam measurements utilizing preliminary correlation data. Assuming a tolerable deflection level of 0.012 inch for a 0.50 foot cement treated base, it was determined that no corrective action would be necessary for this structural section prior to the placement of the final 0.17 foot asphaltic concrete surface course. The Dynaflect, therefore, provided the City of Sunnyvale with an economical deflection evaluation and eliminated the need for corrective measures. It was also used on various other small projects as an investigational tool during Phase I of the evaluation period.

Based on preliminary data, it appeared that the Lane-Wells Dynaflect was a satisfactory deflection measuring device.

At this point in the study, the purchase option was executed on the Dynaflect and the evaluation plan for Phase II was devised.

## PHASE II

This phase of the evaluation program consisted of continuation of correlation work involving traveling deflectometer and Dynaflect and the application of this work to pavement investigational studies.

### Correlation and Investigational Studies

Deflection measurements obtained with the Dynaflect in conjunction with the traveling deflectometer over identical test locations produced the correlation plot which is shown on Figure 11. This data was obtained over 140 different test sections and produced a coefficient of correlation of 0.92 and a standard error of $\pm$ 0.010 inch in terms of traveling deflectometer (Benkelman beam) deflection. These test sections were representative of various soil conditions, structural sections, pavement surface temperatures and asphaltic concrete surface conditions, varying from uncracked to considerable distress.

This data suggests a good correlation between deflection measurements obtained with the Dynaflect and those obtained by the traveling deflectometer. However, the overall standard error of $\pm$ 0.010 inch in terms of deflectometer deflection (Benkelman beam) is considered poor.

In general, asphalt concrete overlay repairs for distressed roadways are most effective for Benkelman beam deflection levels less than 0.040 inch. Roads with deflections above this range generally require more extensive treatment. Based on the data presented on Figure 11, the standard error of estimate for roadways exhibiting deflections less than 0.040 inch is about $\pm$ 0.007 inch. The spread of data in this range is less, primarily because of uncracked pavements.

Although the Dynaflect did not correlate as well to our present equipment, as initially indicated by Benkelman beam studies during Phase I, it is still considered acceptable for work on pavement distress investigational studies of limited scope. It particularly lends itself to city and county work because of its mobility.

During this study, 21 projects representing 120 different test sections have been subject to deflection study for purposes of recommending reconstruction utilizing the Dynaflect and the preliminary correlation curve which was developed with Benkelman beam data or later in this study using the correlation with traveling deflectometer (Benkelman beam) deflection. On these projects, the Dynaflect was used either as a supplemental deflection measuring tool along with the traveling deflectometer, or it was used exclusively on small projects or on projects in remote locations.

When using the Dynaflect for pavement deflection investigational work, the only variation or addition to the California procedure would be the conversion from Dynaflect deflection to an equivalent Benkelman beam deflection level. This can easily be accomplished by converting the evaluated 80 percentile Dynaflect deflection level for a particular test section to an equivalent Benkelman beam deflection utilizing Figure 11 and following the California Division of Highways deflection analysis procedure.[1,5]

Generally speaking, it is not necessary to read the complete series of geophones for most investigational work. The one geophone sensor under the loading is sufficient. However, for semirigid structural sections, such as cement treated bases, reading the complete series is sometimes useful. This may provide some indication of slab strength and help delineate areas of weakness. This area of research will be explored in more detail a little later in this paper.

Dynaflect measurements for an investigational type study are generally obtained at 0.01 mile intervals in the most severely distressed wheel track of each test section which is represented by a minimum of twenty (20) measurements. This was found to statistically provide a good sampling in areas of considerable deflection variation. The number of Dynaflect test sections per mile should be a minimum of one or two depending upon surface condition. With the California traveling deflectometer, generally one 1000 foot test section per lane mile is sufficient because of the larger accumulation of data.

As a means of comparison, various distressed roadways were tested with the Dynaflect and also the traveling deflectometer as part of an operational deflection study. Recommendations for corrective treatments were made based on deflectometer data. Dynaflect measurements were obtained at 0.01 mile intervals and converted to deflectometer deflection (Benkelman beam) by use of Figure 11. Traveling deflectometer readings were obtained at 14-1/2 foot intervals and converted to 100 foot mean deflection measurements for simplicity. Deflection profiles of four selected test sections on three different projects are presented on Figures 12 through 15. From these deflection studies, the resulting mean and evaluated 80 percentile deflections can be compared for both types of measurement.

These figures, in some cases, show considerable variation between individual deflections obtained with the Dynaflect. This is somewhat misleading as the variational effects between individual measurements obtained by the traveling deflectometer are masked out by station averaging. Each point on the deflectometer profile is, therefore representative of seven individual measurements whereas, each point on the Dynaflect deflection profile is representative of one measurement.

These projects present typical examples of how both types of measurement and corrective treatment might be expected to vary during actual investigational work. Figures 12 and 13 indicate close agreement between calculated mean and evaluated 80 percentile deflection levels by both methods, suggesting no variation in design corrective treatment.

The two deflection profiles on Figure 14 produced the same calculated mean deflection level (0.029 inch), but yielded different evaluated 80 percentile design deflection levels (0.035 inch by traveling deflectometer and an equivalent 0.042 inch by Dynaflect). This particular roadway was in generally good condition and carried a high volume of traffic. An asphaltic concrete contact blanket was not applicable, as it would bond to the existing surfacing to form a thicker pavement section requiring a much lower tolerable deflection level. A blanket repair would not provide a sufficient reduction in the existing deflection level because the resulting deflections would never approach the tolerable limit required for the thicker pavement. A cushion course overlay was therefore recommended by deflectometer design and consisted of 0.50 foot of Class 2 aggregate base surfaced with 0.35 foot asphaltic concrete. The 0.042 inch evaluated equivalent deflection level measured by the Dynaflect would increase the required repair by about 14 percent in terms of gravel equivalence which would provide a slight overdesign.

Figure 15 shows the amount of variation which might occur at extreme deflection levels. This particular project produced an evaluated 80 percentile equivalent Benkelman beam deflection level of 0.090 inch by Dynaflect and 0.073 inch by traveling deflectometer. Both deflection levels indicate the need for a major corrective treatment. Assuming that a 0.30 foot asphaltic concrete surfacing is utilized in a cushion overlay repair, a tolerable deflection level of 0.020 inch is indicated by Figure 16* (Traffic Index 8.0). This suggests the need for the following reductions in deflection level:

*Basic criteria used by California Division of Highways for recommending reconstruction of distressed roadways by deflection analysis.

$$\frac{0.090 \text{ inch} - 0.020 \text{ inch}}{0.090 \text{ inch}} \times 100 = 78 \text{ percent (Dynaflect)}$$

$$\frac{0.073 \text{ inch} - 0.020 \text{ inch}}{0.073 \text{ inch}} \times 100 = 73 \text{ percent (deflectometer)}$$

Figure 17*, indicates a need for an increase in gravel equivalence of 20.5 inch by Dynaflect and 18.5 inch by deflectometer. This would yield a slight overdesign by Dynaflect measurement.

These examples illustrate that Dynaflect measurements are comparable to traveling deflectometer or Benkelman beam measurements. The Dynaflect does, however, generally yield a more conservative design than that produced by the Benkelman beam principle. The results of deflection measurements on other comparative operational studies are shown on Table 1 which presents mean and evaluated 80 percentile levels for Dynaflect and traveling deflectometer over identical test sections. The distribution and correlation of this data is also shown on Figures 18 and 19.

Figure 18 presents a comparison of the mean deflection levels determined by Dynaflect and deflectometer. This data reveals a weak positive correlation about the line of equality and suggests higher deflection measurement by Dynaflect. The coefficient of correlation was found to be 0.93 about the regression line for the full range of data and 0.85 for all measurements between 0 and 0.040 inch, which would be representative of a roadway which could be overlayed with asphalt concrete. The standard error for the full range was found to be ± 0.009 inch in terms of equivalent Benkelman beam deflection (from Dynaflect measurement). This value compares closely to the ± 0.010 inch standard error (Sy) presented on Figure 11. The standard error was ± 0.005 inch for all measurements below 0.040 inch and was ∓ 0.012 inch for the full range about the line of equality.

Figure 19 presents a comparison of the 80th percentile deflection levels for the same data discussed above. The distribution was about the same as with the mean deflection levels. The coefficient of correlation was 0.90 for the full range and 0.79 for measurements below 0.040 inch deflection. The standard error was ± 0.013 inch for the full range and ± 0.007 inch for measurements below 0.040 inch deflection. The data about the line of equality produced a standard error of ± 0.015 inch.

*Basic criteria used by California Division of Highways for recommending reconstruction of distressed roadways by deflection analysis.

The data above the 0.040 inch deflection level suggests a higher deflection measurement by Dynaflect resulting in a more conservative overlay design or corrective treatment. This is confirmed by the design overlay recommendations resulting from data presented on Figures 12 through 15.

Deflected Basins

A considerable amount of data has been collected on the slope and shape of deflected basins from Dynaflect measurements over various structural section materials. According to theory, the strength of the section can be determined or indicated by the slope of the deflected basin. This involves obtaining readings on all geophone sensors to determine the maximum slope of the basin. When represented on semi-logarithmic paper, this basin approaches a straight line. The flatter the slope, the stronger and stiffer the section. Figure 20 presents deflected basins which were measured on three (3) different types and thicknesses of structural section on the same project. Basin 1 represents a cement treated base which is stiffer and stronger than either structural section 2 or 3 which have untreated aggregate bases. Although structural section 2 has 0.50 foot of asphaltic concrete, it is only slightly stiffer than section 3 which has only 0.25 foot of asphaltic concrete. This figure, therefore, demonstrates that Dynaflect measurements do suggest some indication of slab strength.

Data for Figure 21 was obtained over the subgrade material on the Ball Test Road in Contra Costa County, California. As mentioned earlier in this report, the subgrade on this facility was constructed in six different units using two different types of compactive effort and varying moisture levels. Inspection of the resulting deflected basins on Figure 21 indicates an increase in strength with an increase in relative compaction. This is true for both methods of compaction and is better represented by the maximum deflection rather than the slope of the deflected basin. However, the moisture level of the subgrade material is of considerable influence in determining changes in relative compaction by use of the Dynaflect. This was verified by applications on other subgrade soils where large differences in moisture and density produced inconclusive results. However, further study is needed in this area before any definite conclusions can be reached.

Dynaflect deflection basin measurements over the aggregate base material on the Ball Test Road produced the results shown on Figure 22. If we look at maximum deflection level alone, section 1 is the weaker section and 4, 5 and 6 are the stronger sections as was also indicated by Figure 21.

Dynaflect deflection basin measurements on the completed roadway are presented by Figure 23. This figure demonstrates the same strength trends as shown on Figures 21 and 22. This follows true because the aggregate base and asphaltic concrete surfacing were placed and constructed with as much uniformity and consistency as possible. The only variables affecting the deflection levels were those incorporated in the subgrade (moisture and compactive effort). The deflection attenuation properties of the three (3) structural section elements are presented by the individual deflection basins on Figure 24. Here, it can be seen that the structural section becomes stronger as each element is placed. This is suggested by both the maximum deflection level and the slope of the deflected basin.

The maximum critical slope of the deflected basin for structural sections consisting of asphalt concrete over cement treated base can be determined by Figure 25. This figure was included in a research report of the California Division of Highways dated June 1968.[6] On this research project, the Dynaflect was used to evaluate 35 different cement treated base pavements in California at the rate of two test sections per project. The age of these pavements varied from two to twelve years. Figure 25 suggests a good correlation between maximum Dynaflect deflection and maximum slope of the deflected basin as determined by Dynaflect measurement. The point of demarcation between cracked and uncracked pavement is difficult to define; however, the authors suggest a critical maximum slope of 0.002 percent for a cement treated base. This would be in the range of approximately 0.0008 inch Dynaflect deflection or 0.010 inch in terms of Benkelman beam deflection which is in close agreement with the 0.012 inch suggested by California Division of Highways pavement deflection criteria for a 6 inch cement treated base. If this value were exceeded, cracking of the surfacing would probably develop during the design life of the facility.

The critical slope for deflected basins of asphalt concrete pavement over flexible bases can be determined from Figure 26. This figure also presents a good relationship between maximum Dynaflect deflection and maximum slope of the deflected basin. Since most of the uncracked pavements above 0.0015 inch maximum deflection are two to three years of age, a critical slope of the deflected basin would be about 0.005 percent for an asphalt concrete over a flexible base. In terms of maximum deflection, this would be about 0.030 inch by Benkelman beam. However, this may be misleading since the majority of the pavements with deflections below this value were less than five years old. Based upon fatigue and deflection tests, the California Division of Highways deflection criteria suggests a maximum Benkelman beam deflection of 0.020 inch to prevent cracking in a 3 inch asphalt concrete surfacing and this value would vary depending upon Traffic Index. Figures 25 and 26 tend to substantiate California's deflection criteria, therefore, suggesting the maximum slope of a deflected basin must relate to slab strength.

## Operational Application on Basement Soil

Dynaflect deflection measurements were taken over three shoulder areas on Ygnacio Valley Road in Contra Costa County which were dugout prior to deflection measurement. These measurements were, therefore, obtained over the exposed basement soil which was classified as an AASHO A6 material which varied in character from a clay-silt to a silty-clay. The Dynaflect operated quite successfully over this material as shown by the results presented on Figure 27. The use of the Dynaflect on other projects, for instance those involving its application directly over cohesionless sandy type soils, gave results which were not as successful because the vibratory load would tend to damp out at short distances from the source. This would indicate that the nature of the unsurfaced material upon which the Dynaflect is operated has considerable bearing on valid results. Although the deflection results on Ygnacio Valley Road were good, no clear-cut trend in the shape of the deflected basins is indicated for the changes in moisture content and relative compaction. However, section 1 with the 16.2 percent moisture content did produce the weaker section with the highest deflection level. This again suggests that the moisture content rather than the density has a greater effect on the deflection results.

Some work has been done to determine if a correlation exists between the maximum slope of the deflection basin produced by the Dynaflect and the maximum slope of the deflection basin measured on the deflection trace of the California traveling deflectometer. A definite relationship exists as shown on Figure 28, however there is no clear-cut value for the maximum slope of the deflection basin trace produced by the deflectometer at the maximum Dynaflect basin slopes of 0.002 percent and 0.005 percent suggested on Figures 25 and 26.

## Evaluation of Dynaflect on PCC Pavement

The Corps of Engineers has done considerable research in the evaluation of the Dynaflect on various portland cement concrete airport pavements. The report of this work[7] suggested the following findings:

1. Dynaflect deflection corresponds within reasonable tolerances to a theoretical deflection produced from a 500 pound static load on PCC pavement over clay subgrade.

2. Dynaflect could be used to obtain subgrade moduli.

3. On cohesive subgrade, Dynaflect measurements could be correlated to plate bearing tests.

4. Dynaflect measurements were found to be inconsistent on sand subgrades and it appeared that correlation with plate bearing for arriving at modulus K was not feasible with this material.

5. Load transfer at joints could be detected by Dynaflect measurement.

6. Indications of slab integrity could be obtained by use of Dynaflect.

For the purpose of California's evaluation of the Dynaflect, three different PCC pavements in the Sacramento area were tested. Two were recently constructed and were not as yet subject to traffic. The third was an old PCC pavement which is no longer in service. A total of seven test sections were selected over these facilities. Deflection measurements were obtained with the Dynaflect on each of these test sections at the center of five adjoining slabs and also across the transverse contact joints of these slabs. The Dynaflect was positioned with the force wheels and number 1 geophone on the forward slab with the contact joint half way between the number 1 and number 2 geophone. Measurements were then obtained on all geophone sensors. This was done to determine the load transfer across the joints and the difference in bearing provided by the subgrade at the joints and in the center of the slabs.

At one test location on one of the newly constructed PCC pavements (03-Sac-80), subgrade modulus K was determined by plate bearing tests by the Portland Cement Association as part of another research study. For this evaluation, the Dynaflect was used on the surface of this particular PCC pavement which was 0.75 foot thick and based on the deflection results, a subgrade modulus K was determined by Westergaard Analysis using the following equation:

$$Z = \frac{cp}{Kl^2} = \text{Dynaflect deflection (inches)}$$

Where: c = 0.23 (for deflection between Dynaflect wheels 20 inches apart)

p = load (250 pounds per wheel at 20 inches center to center)

l = radius of relative stiffness

$$l = \sqrt[4]{\frac{Eh^3}{12(1-u^2)K}} \qquad \text{(Reference 8)}$$

E = $4.0 \times 10^6$ psi, modulus of elasticity for concrete

u = 0.15, Poisson's ratio for concrete

h = slab thickness

Deflection measurements were obtained in the center of the adjoining slabs in the vicinity of the plate bearing tests and across the joints to determine load transfer. The deflection at the center of the slab was used for the plate bearing calculation. The results are shown on Figure 29 along with theoretical curves for modulus K. Figure 29 suggests a value between 100 and 150 pounds per cubic inch for modulus K. This is considerably lower than the 350 pounds per cubic inch determined by plate bearing tests. Since this is a typical California PCC pavement with a standard cement treated base subgrade, these results would indicate that modulus K cannot be accurately obtained with the Dynaflect on California PCC pavements. However, further tests are required to make a firm conclusion.

Figure 30 presents a comparison of load transfer across the transverse joints on the three PCC projects which were tested. Project A (03-Yol-40) consists of a 7 inch PCC pavement with formed joints over an untreated aggregate base. The project is no longer in service. Deflected basins A-1 and A-2 which were representative of this project reveal a large difference in deflection magnitude between geophone No. 1 and No. 2. These results would probably be typical of most formed PCC transverse joints over untreated bases. Deflection basins produced on Projects B and C which have sawed transverse joints over a cement treated base, indicate considerable interlock between slabs. These two pavements are new and have not as yet been subject to traffic. The slope of deflection basins B-1 and B-2 suggest a stiffer section than Basin C, even though the magnitude of the deflections are higher.

A comparison between the shape of the deflected basin produced at the slab center and that produced across the transverse joint is shown on Figure 31 for the three projects tested.

## Detection of Seasonal Variations on Thin Surfaced Roadways

An attempt was made during this evaluation study to determine if the Dynaflect was capable of detecting variations in deflection level resulting from seasonal changes. The results of this study are shown by Figures 32 and 33. Here, two different roadways are represented with three series of measurements. The first was obtained in the early fall (9-14-67) with the roadways in their driest condition. The second series (12-1-67) of measurement followed one week of heavy rain and the third was obtained in the late spring (5-27-68) with the roadways in their wettest condition.

The profiles on Figure 32 present low to moderate levels for a structural section consisting of a series of seal coats over a thin base course. They do not suggest any clear-cut trend in the deflection levels, but do show good reproducibility between individual profiles. The calculated mean deflection levels, however, show a slight increase through the winter months with the deflection level the highest in the late spring (5-27-68).

Figure 33 represents an unsurfaced gravel road with a high deflection level. These deflection profiles also show no real trend in deflection level, but the mean deflection levels indicate a slight increase in deflection through the winter months with the highest measurement again in the late spring.

Even though the individual measurements vary considerably, the overall data seems to indicate that the Dynaflect is capable of detecting changes in deflection level on unsurfaced and on thin surfaced roadways due to seasonal effects.

## Use of Dynaflect on Other Research Projects

Numerous uses of the Dynaflect were made on various other research projects during the evaluation program. Some of these applications have already been defined in previous sections of this report. The Dynaflect was used to scan various roadways to determine areas of high deflection level for purposes of their possible inclusion in Research Project EA633128, "Statewide Flexible Pavement Performance and Deflection Study". It was also utilized for deflection measurement on five different projects which were constructed with resilient materials within the structural section as part of Research Project EA633317, "Follow-up Study for the California Resilience Design Method". It was also used in an attempt to detect changes in deflection level due to changes in soil density. This showed some promise but was found to be inconclusive based on limited testing.

Future Possible Areas of Dynaflect Research

1. It is often desirable to overlay an asphaltic concrete pavement with portland cement concrete. A means to determine a bearing modulus "K" that will take into account the strength of the existing base and surfacing and the benefit from traffic compaction is sorely needed. Such a value would generally provide a more economical design than values of "K" obtained from conventional R-value testing. Future research is, therefore, necessary to develop a correlation between Dynaflect deflection and modulus K by plate bearing tests on asphalt concrete pavements.

2. Additional Dynaflect research is necessary to evaluate the relationship between soil deflection and soil density.

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2. Scrivner, F. H., Swift, G. and Moore, W. M., "A New Research Tool for Measuring Deflection of Pavements", Proceedings, 45th Annual Meeting of the Highway Research Board, Washington, D. C., January, 1966.

3. Culley, R. W., "Evaluation of a Dynamic Deflection Determination System (Lane-Wells Dynaflect)", Technical Report 4, Saskatchewan Department of Highways, Regina, Saskatchewan, Canada, October, 1966.

4. Skok, Jr., E. L., "Use of Texas Dynaflect Apparatus on Minnesota Test Sections (1966)", Investigation 183, Special Report 1, Department of Civil Engineering, University of Minnesota, Minneapolis, Minnesota, November 1966.

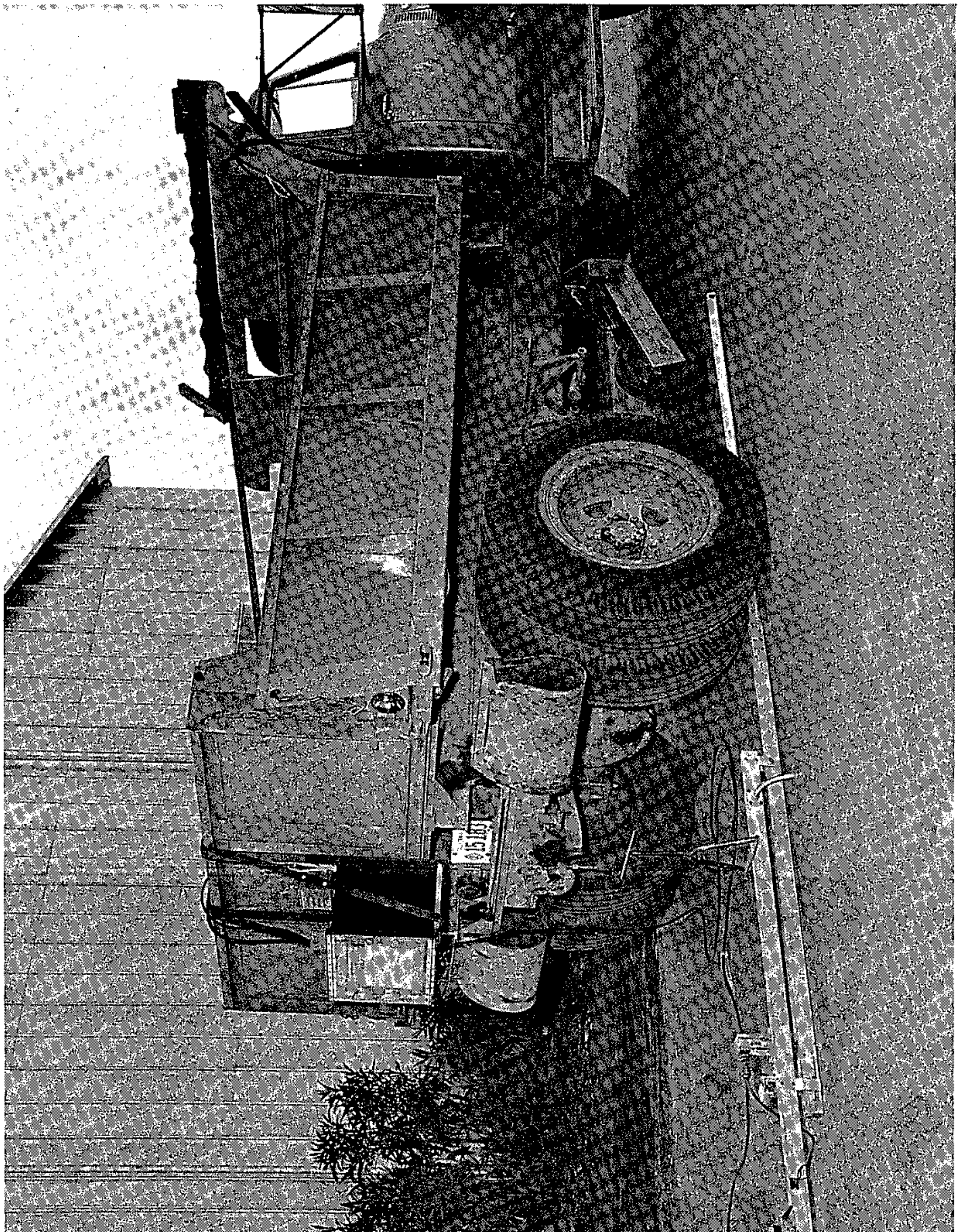
5. Forsyth, R. A., "Use of Deflection Data for Road Repairs and Improvements", Proceedings, 9th Annual Highway and Public Works Conference, University of the Pacific, March, 1966, pages 81-89.

6. Zube, E., Gates, C. G., Shirley, E. C. and Munday, H. A., "Investigation and Appraisal of the Performance of CTB as Used in Composite Pavements in California", Research Report, Materials and Research Department, California Division of Highways, Sacramento, California, June 1968.

7. Pace, G. M., "Evaluation of the Dynaflect for the Non-Destructive Testing of Portland Cement Concrete Pavement", Technical Report No. 4-61, Department of the Army, Ohio River Division Laboratories, Corps of Engineers, Cincinnati, Ohio, August, 1967.

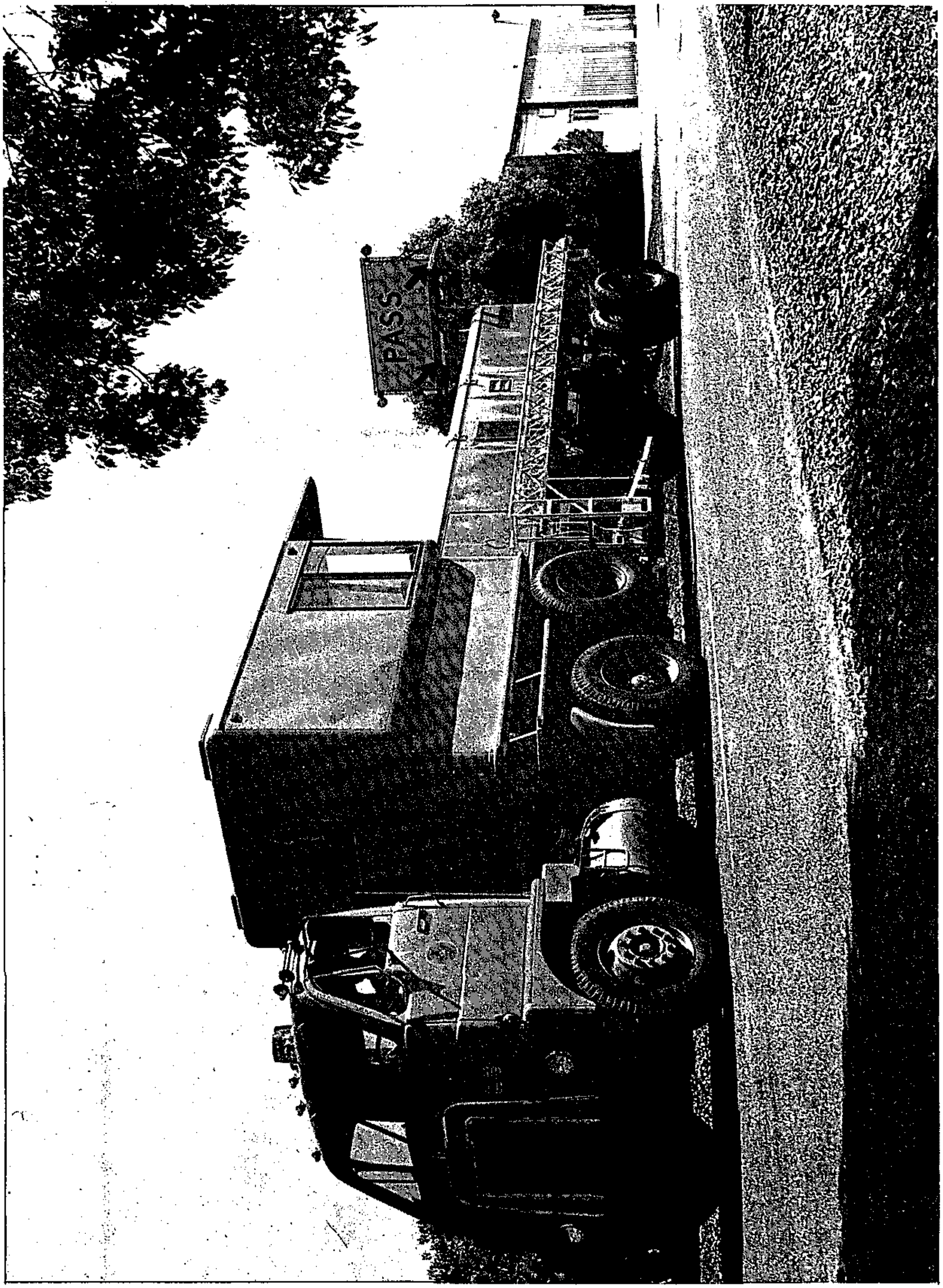
8. Portland Cement Association, "Design of Concrete Airport Pavement", Chicago, Illinois, 1955.

FIGURE 1



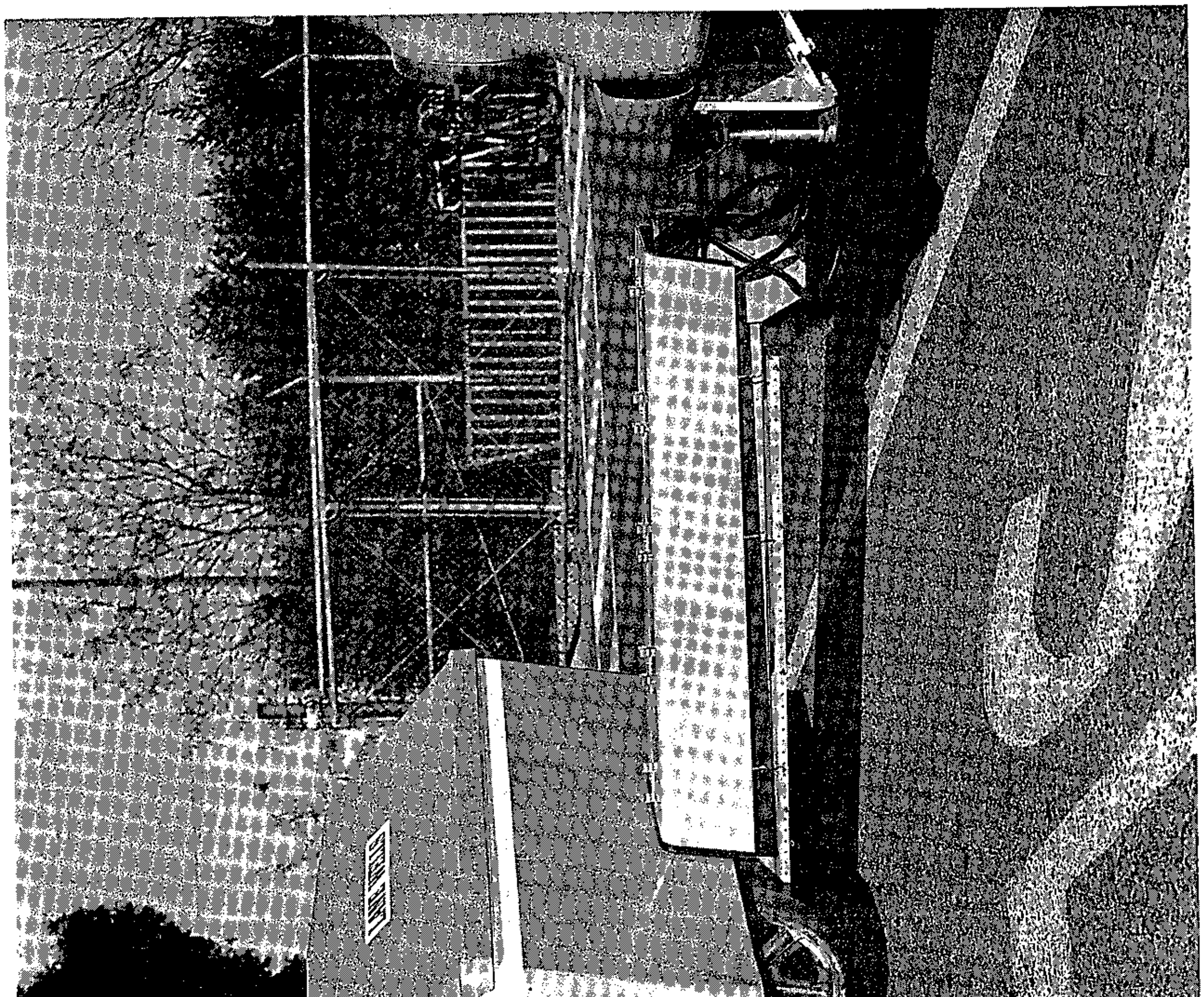
BENKELMAN BEAM WITH TEST TRUCK

Figure 2



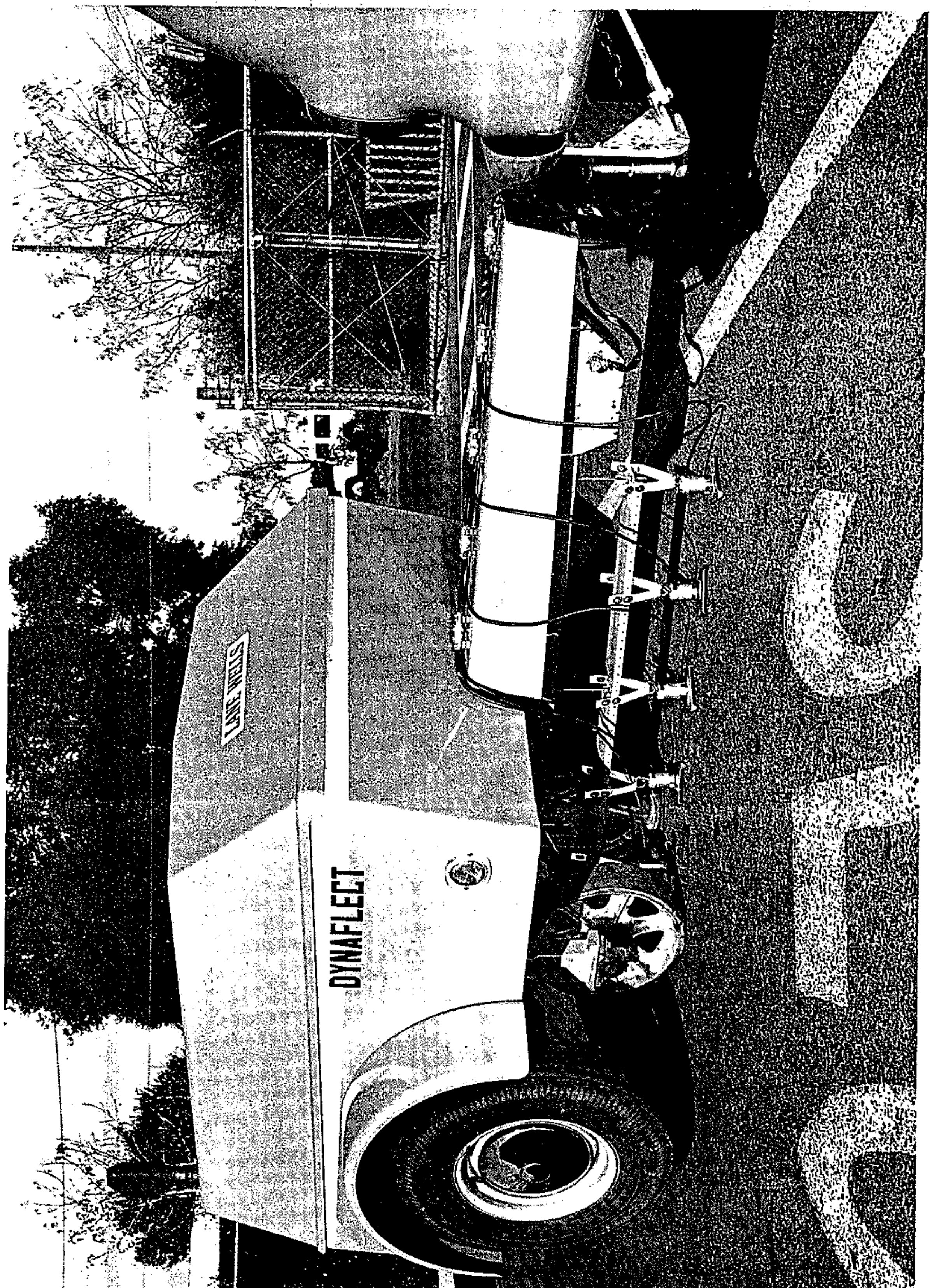

TRAVELING DEFLECTOMETER

FIGURE 3



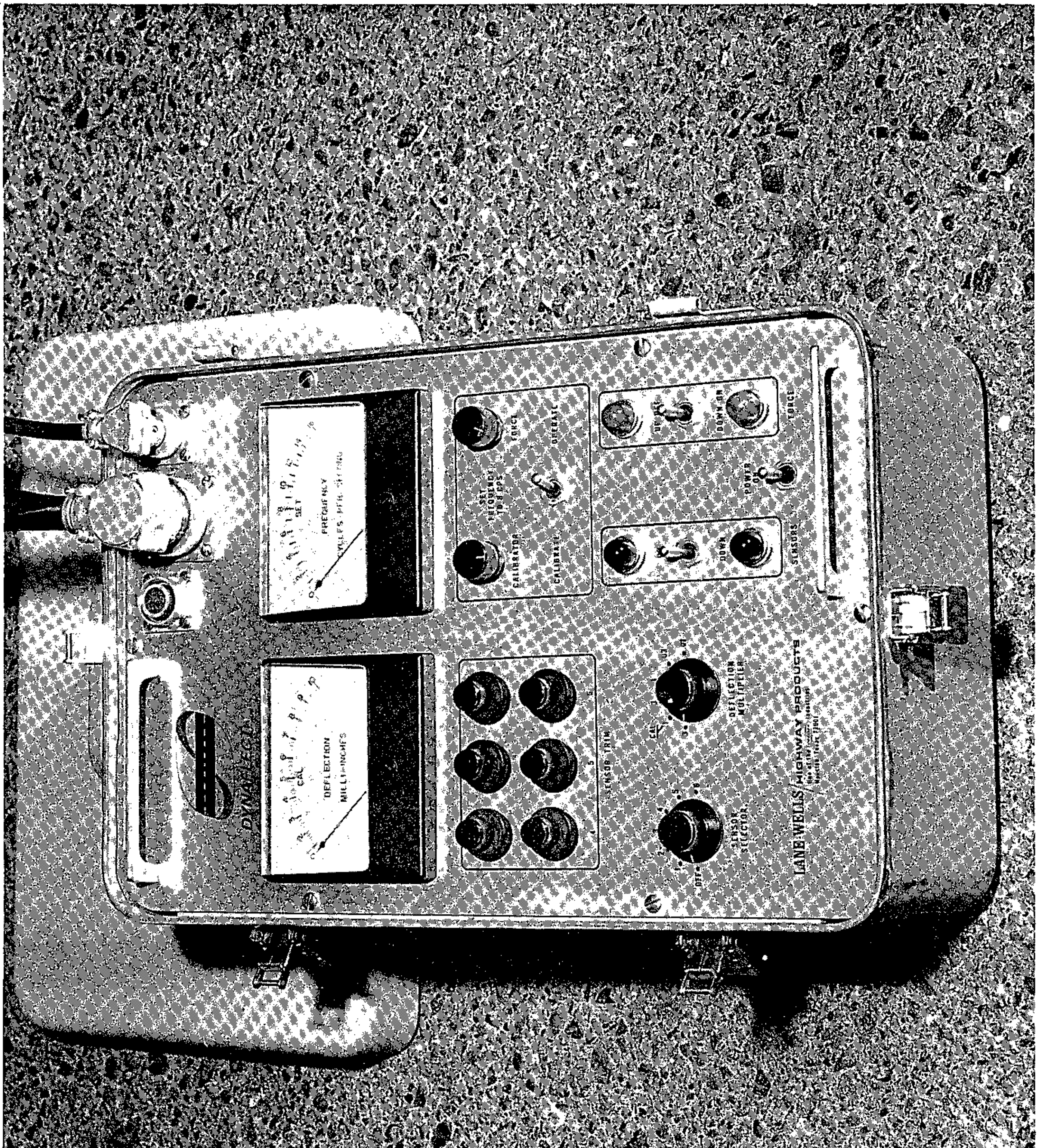

DYNAFLECT IN HIGHWAY TRAVEL POSITION

Figure 4



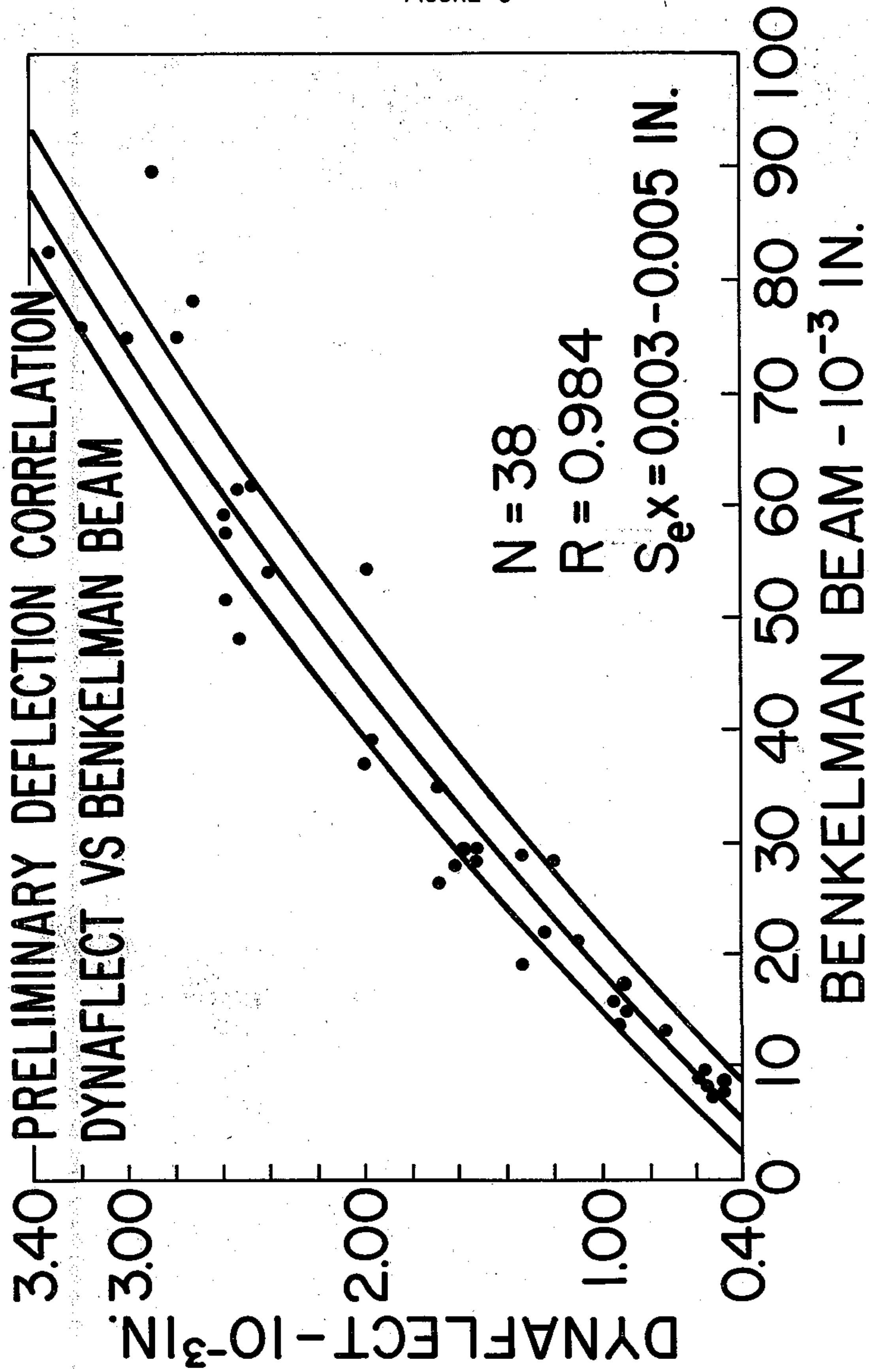

DYNAFLECT IN TEST POSITION WITH FORCE WHEELS AND GEOPHONES DOWN

Figure 5




DYNAFLECT CONTROL BOX

FIGURE 6


PRELIMINARY DEFLECTION CORRELATION
DYNAFLECT VS BENKELMAN BEAM
N = 38
R = 0.984
$S_eX$ = 0.003-0.005 IN.
BENKELMAN BEAM - $10^{-3}$ IN.
DYNAFLECT - $10^{-3}$ IN.
0 10 20 30 40 50 60 70 80 90 100
0.40 1.00 2.00 3.00 3.40

# REPEATABILITY OF LANE-WELLS DYNAFLECT MEASUREMENTS

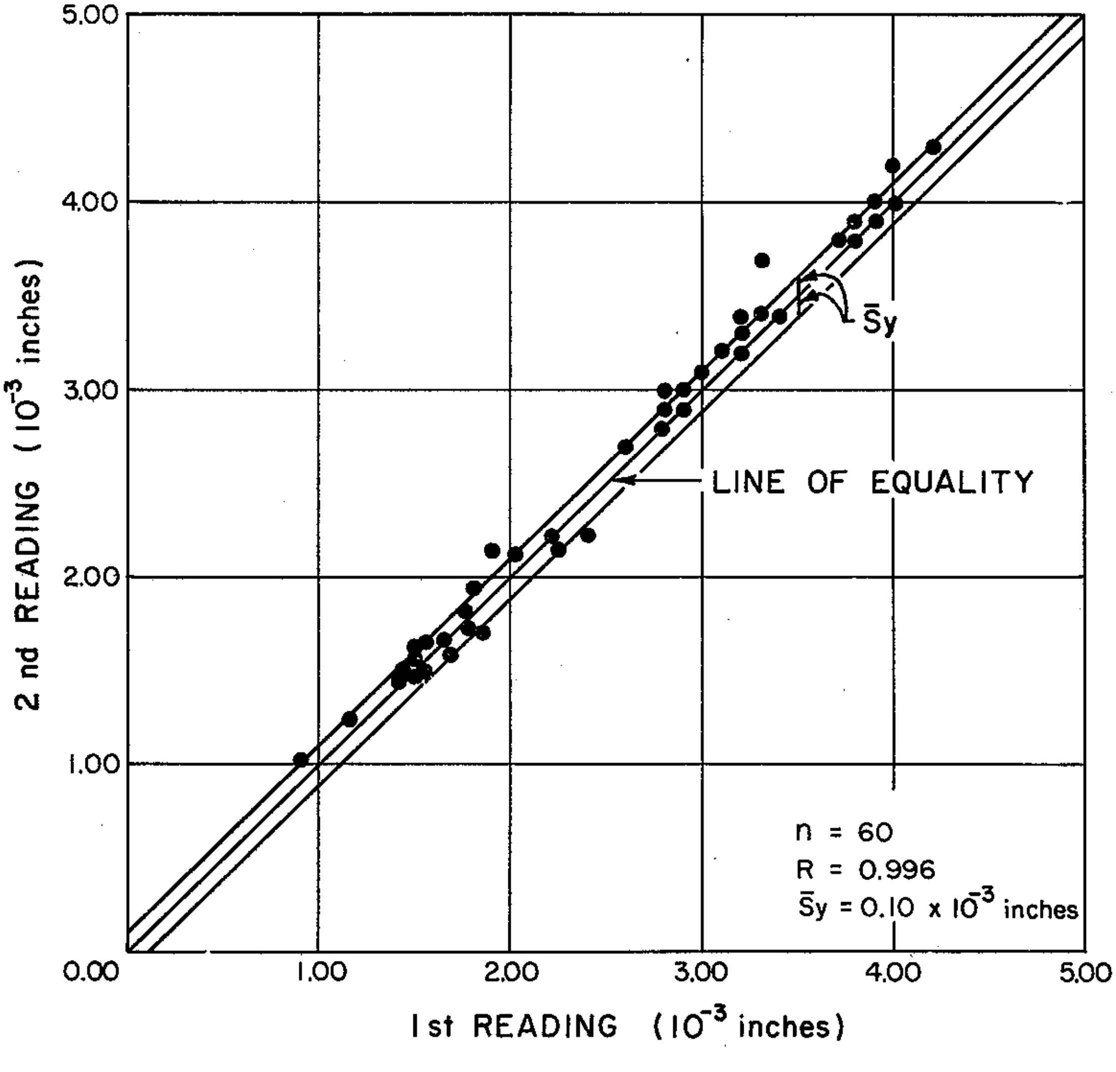


Figure 8

REPEATABILITY OF
BENKELMAN BEAM MEASUREMENTS

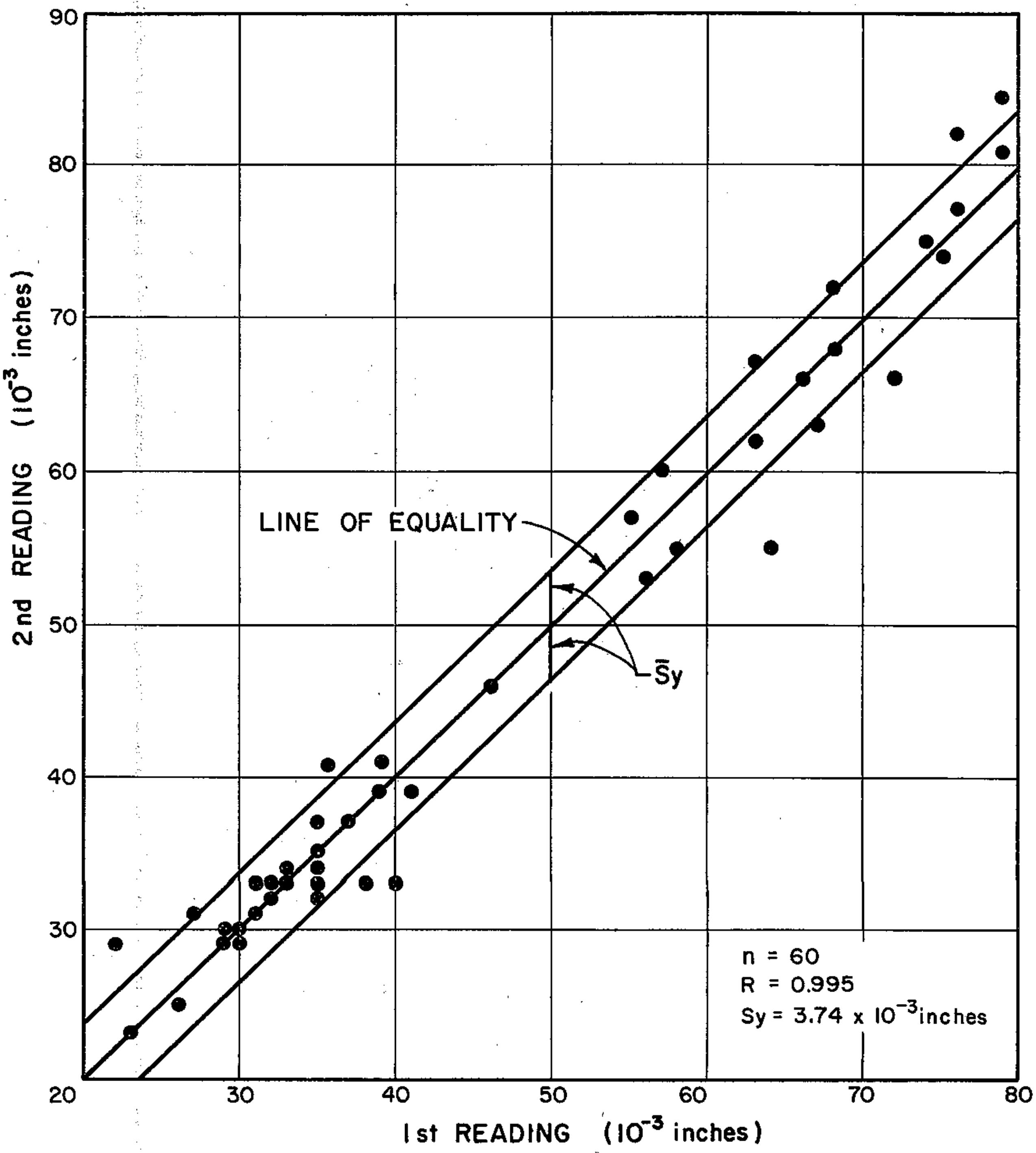
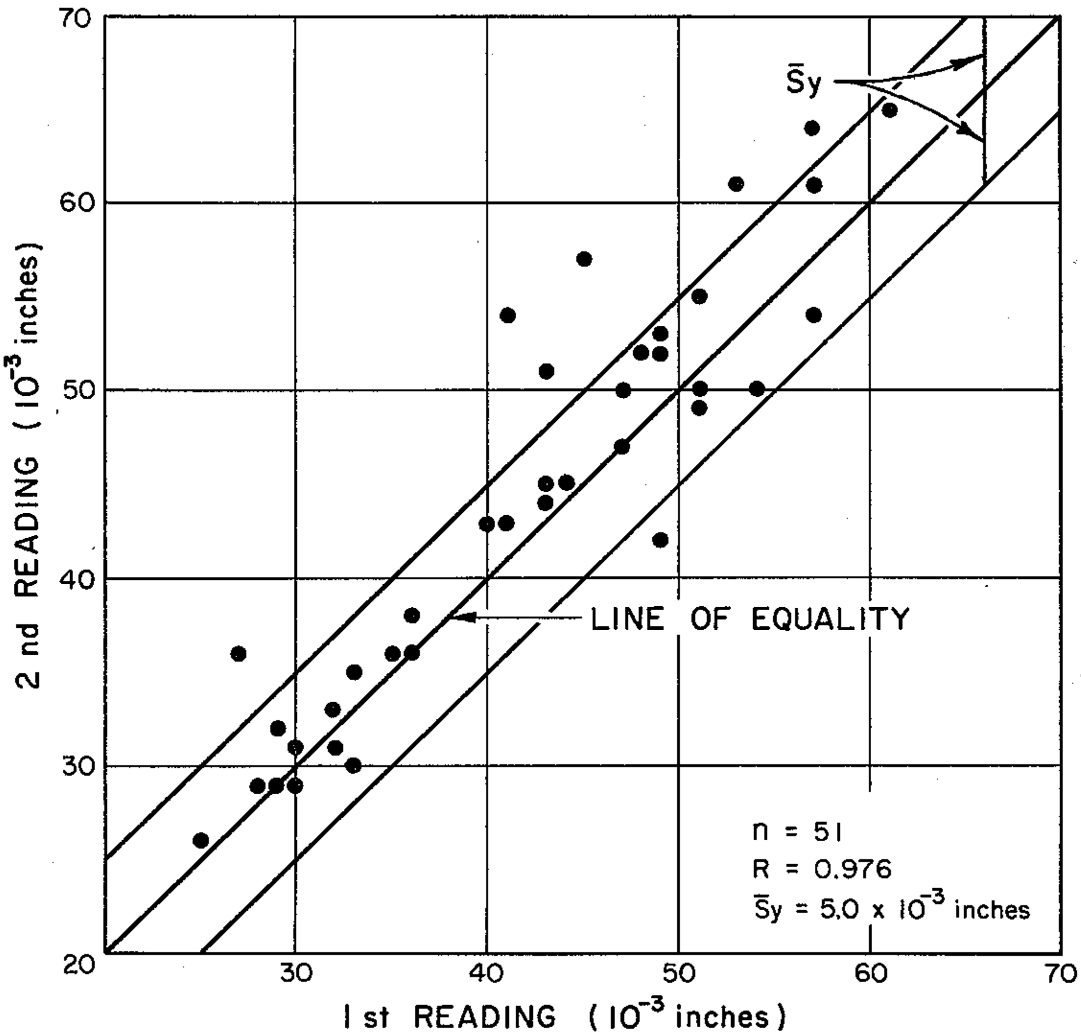


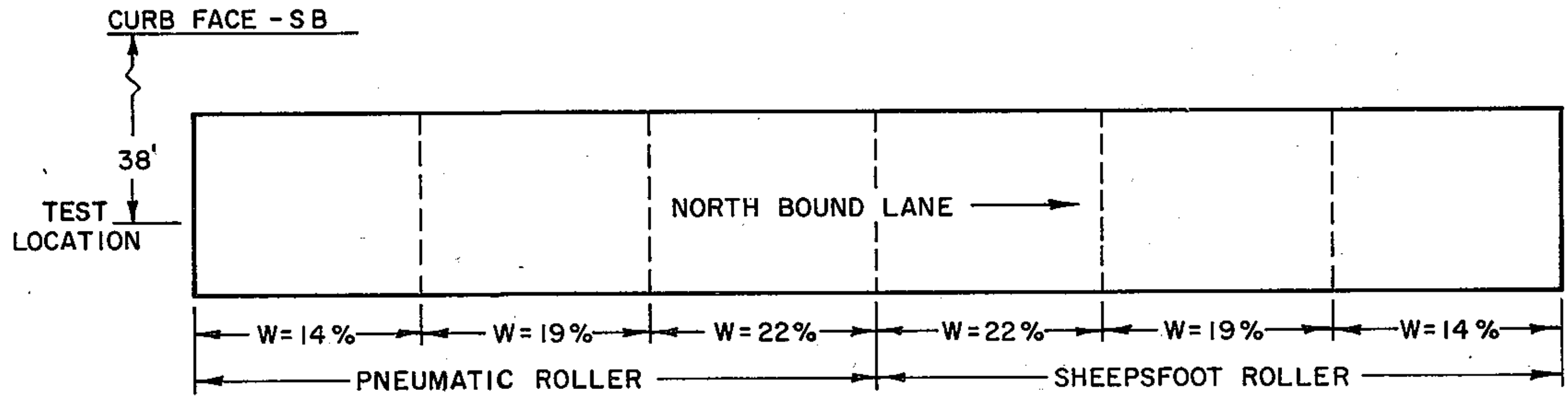
Figure 9

# REPEATABILITY OF TRAVELING DEFLECTOMETER MEASUREMENTS



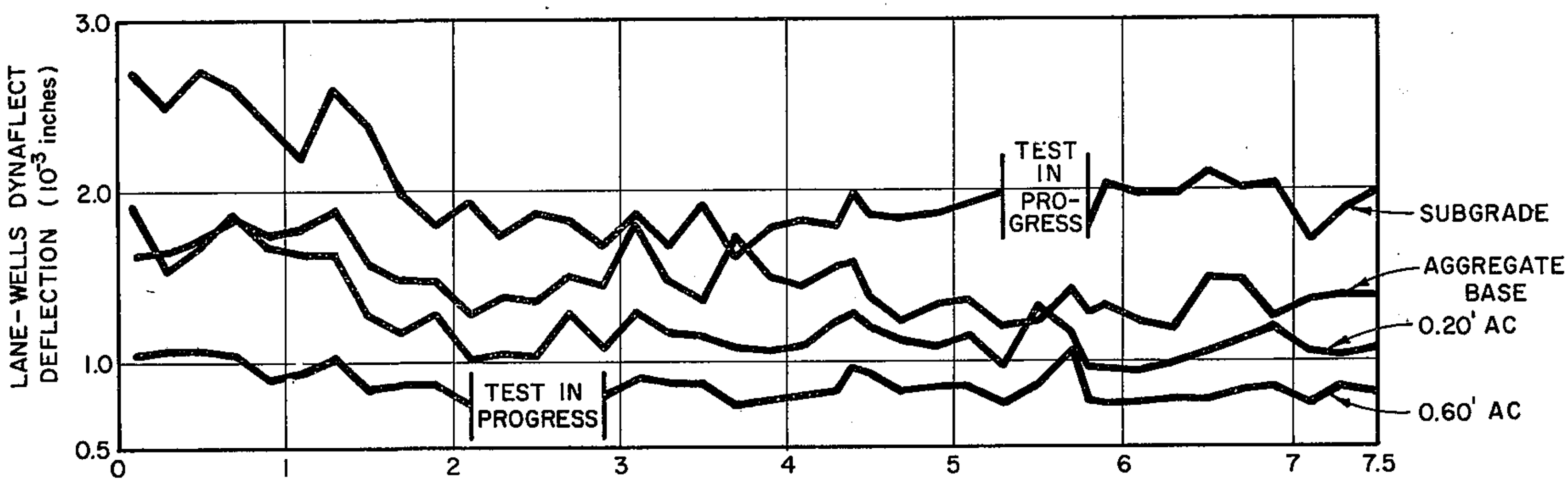
# DYNAFLECT DEFLECTION PROFILES

## 04 – CC – Ball Test Road




PLAN

W = DESIGN MOISTURE CONTENT




DEFLECTION PROFILES

Figure 11

# COMPARISON OF DYNAFLECT AND TRAVELING DEFLECTOMETER

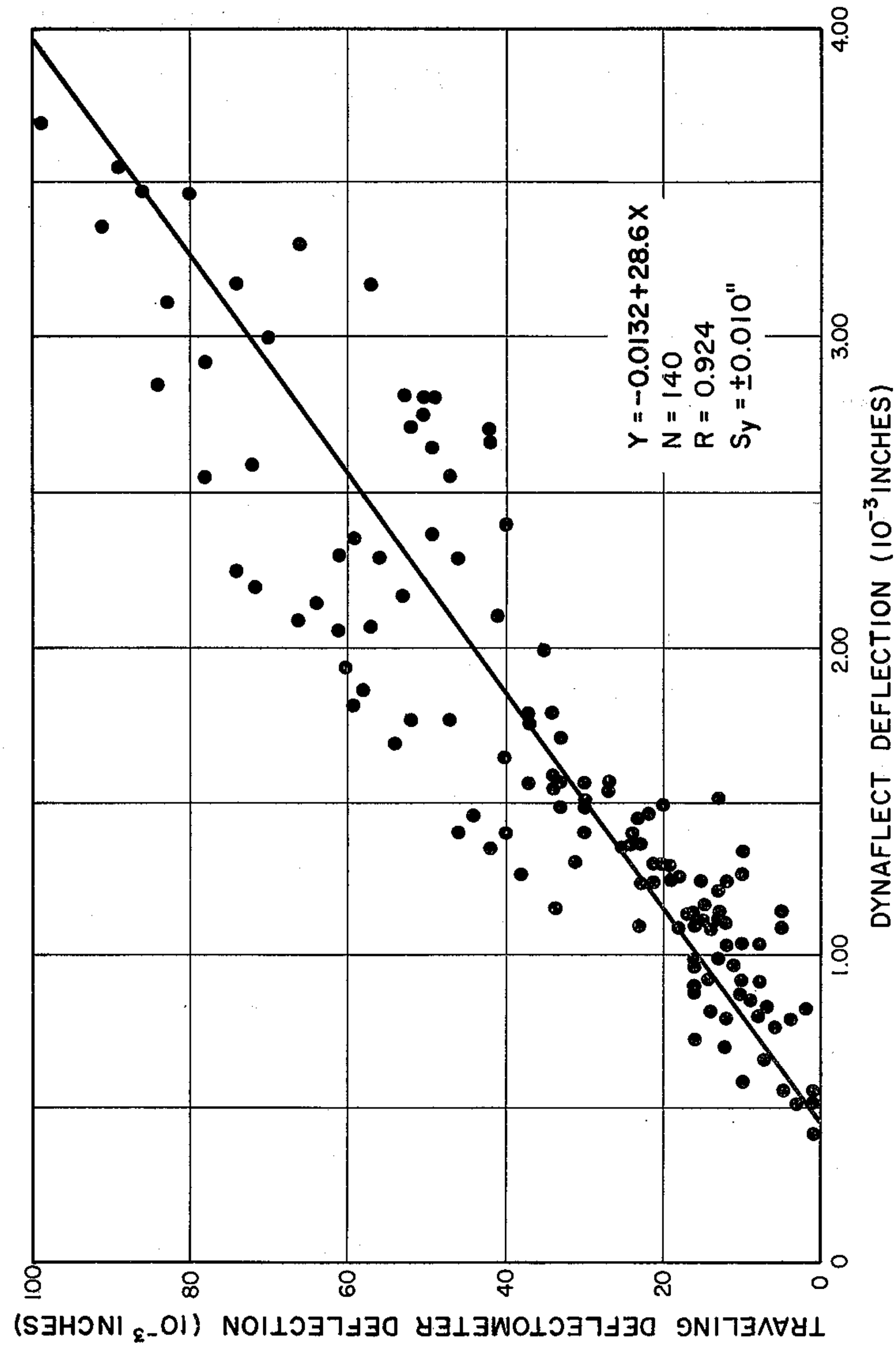
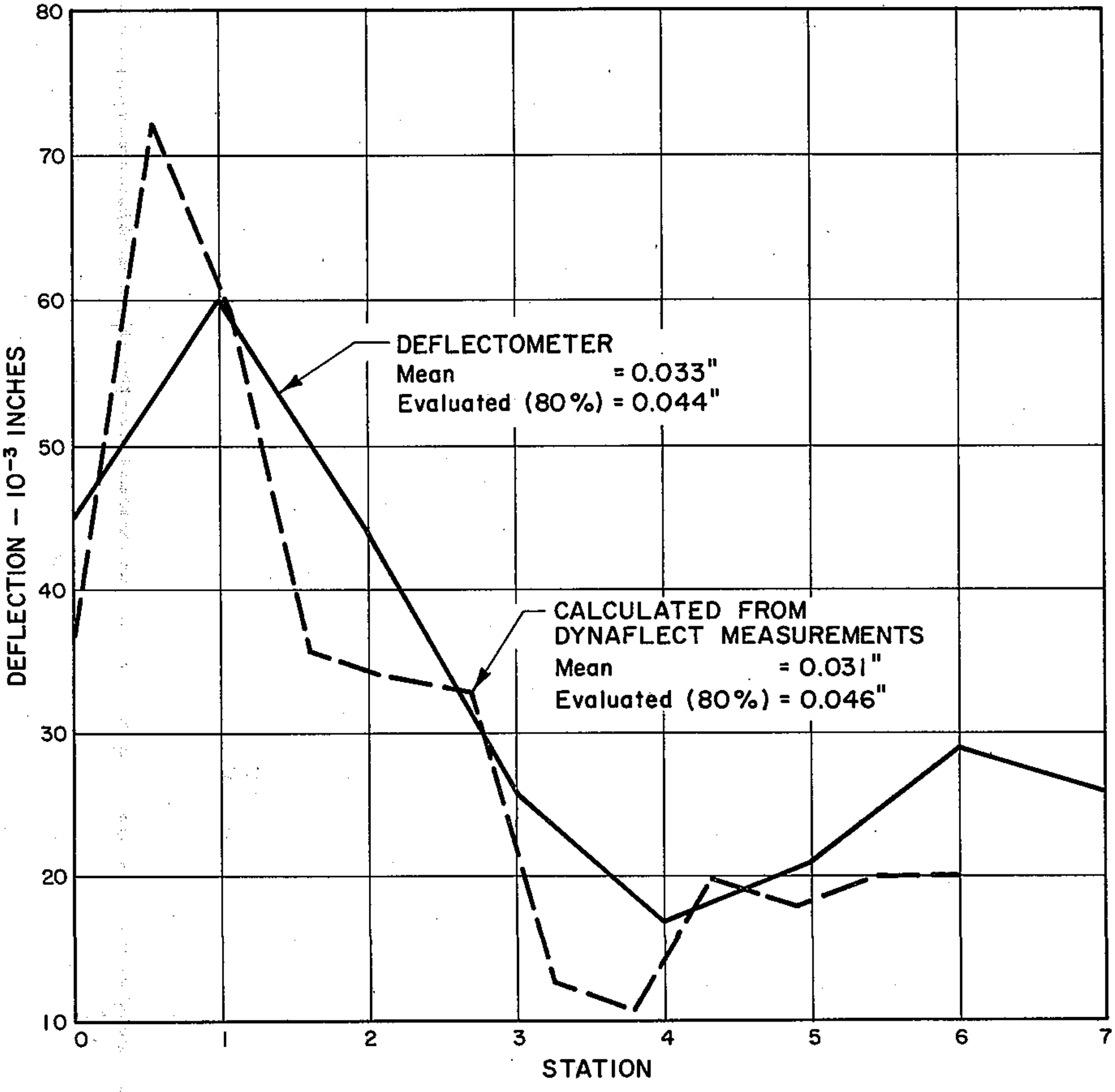


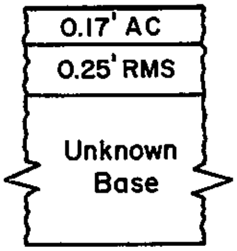
Figure 12

# COMPARISON OF MEASURED DEFLECTION BY DEFLECTOMETER AND DYNAFLECT

ROAD 07-LA-60-18.7/22.8-OWT
TRAFFIC INDEX = 9.0




EXISTING
STRUCTURAL SECTION



# COMPARISON OF MEASURED DEFLECTION BY DEFLECTOMETER AND DYNAFLECT

ROAD 08-Riv-395 PM 8.4/20.3
TRAFFIC INDEX = 10.0

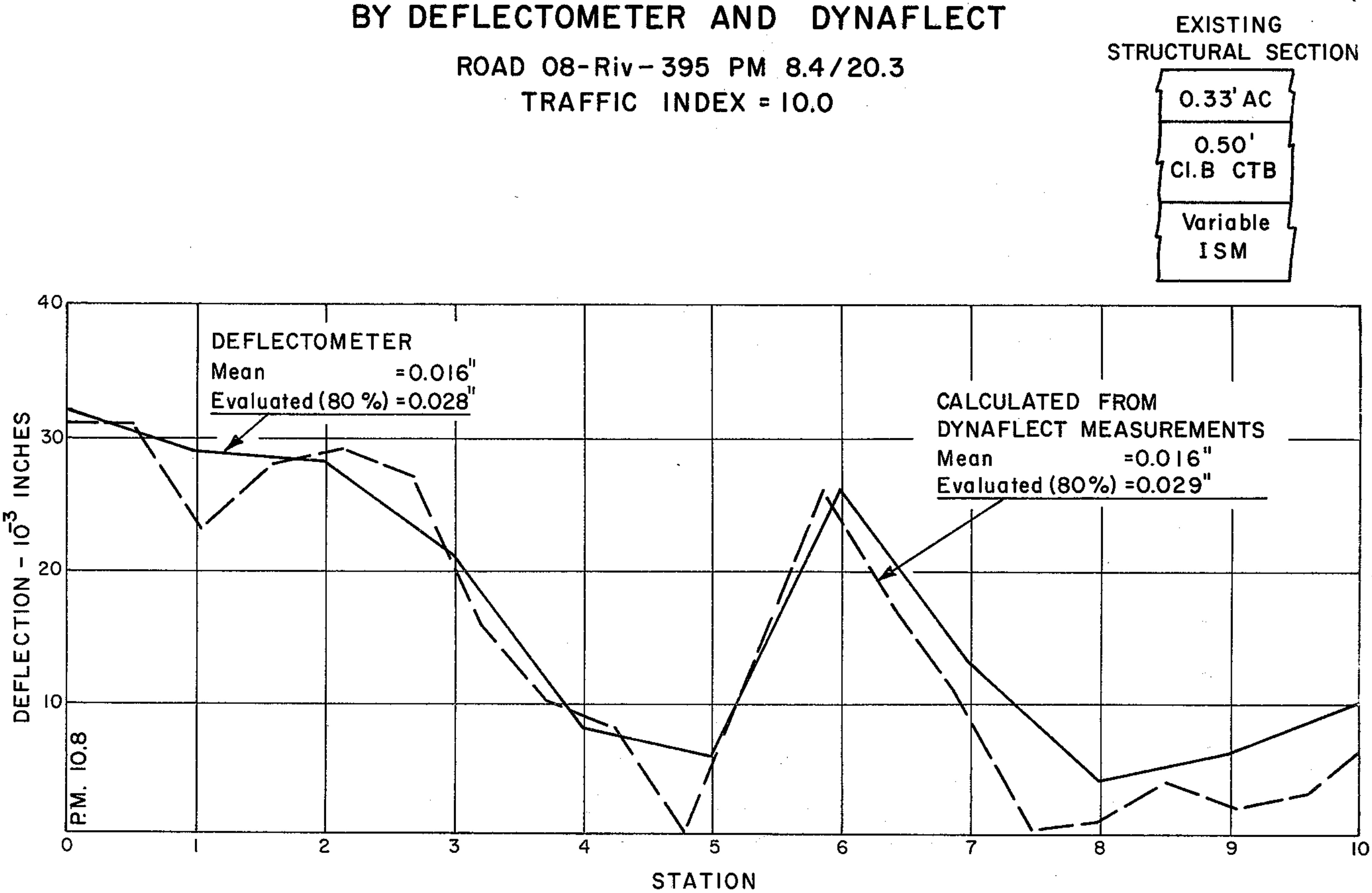



Figure 13

# COMPARISON OF MEASURED DEFLECTION BY DEFLECTOMETER AND DYNAFLECT

ROAD 08-Riv-395 PM 8.4 / 20.3
TRAFFIC INDEX = 10.0

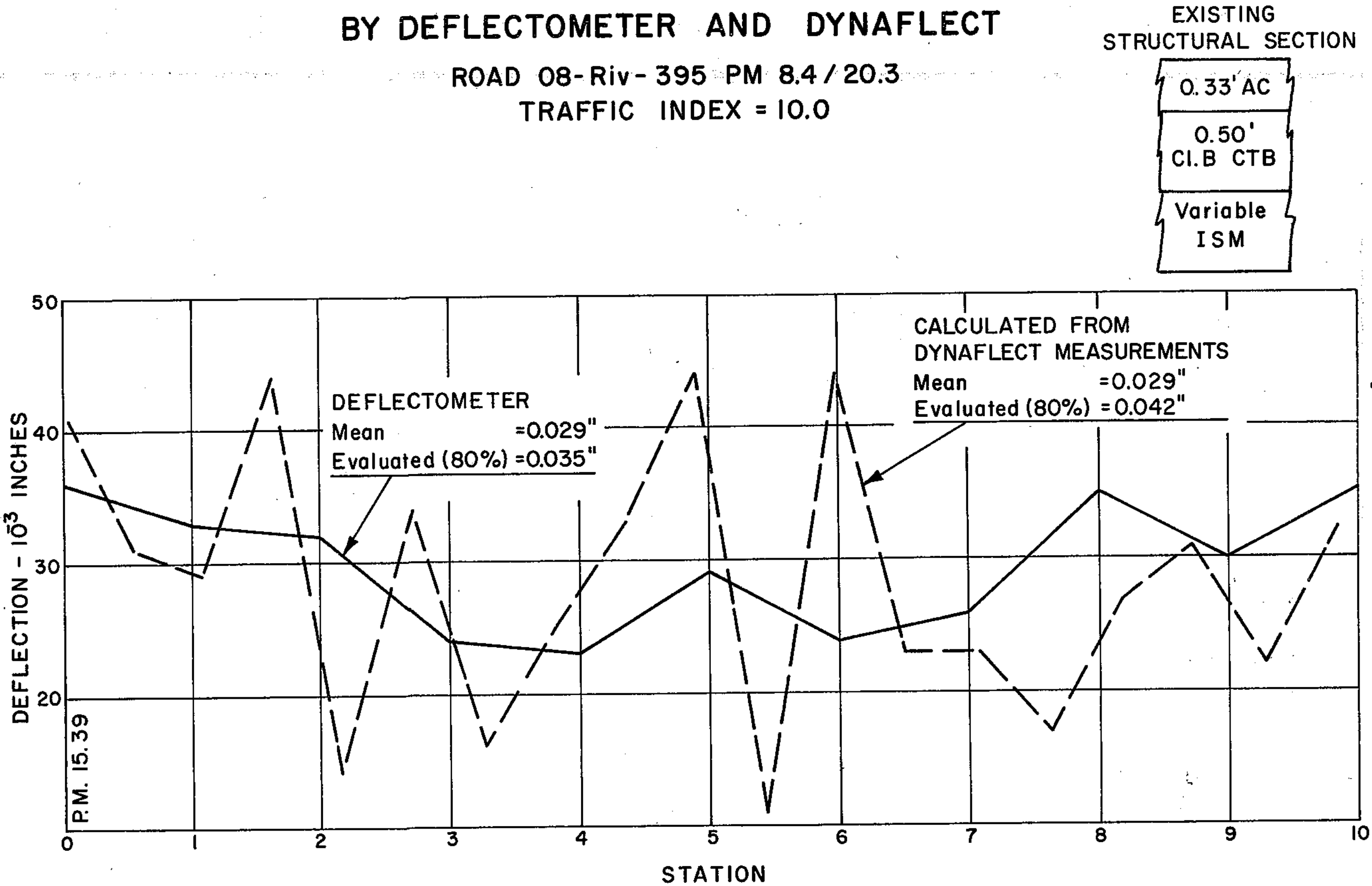



Figure 14

# COMPARISON OF MEASURED DEFLECTION BY DEFLECTOMETER AND DYNAFLECT

ROAD 10- Mer-MERCY SPRINGS ROAD-O.W.T.

TRAFFIC INDEX = 8.0

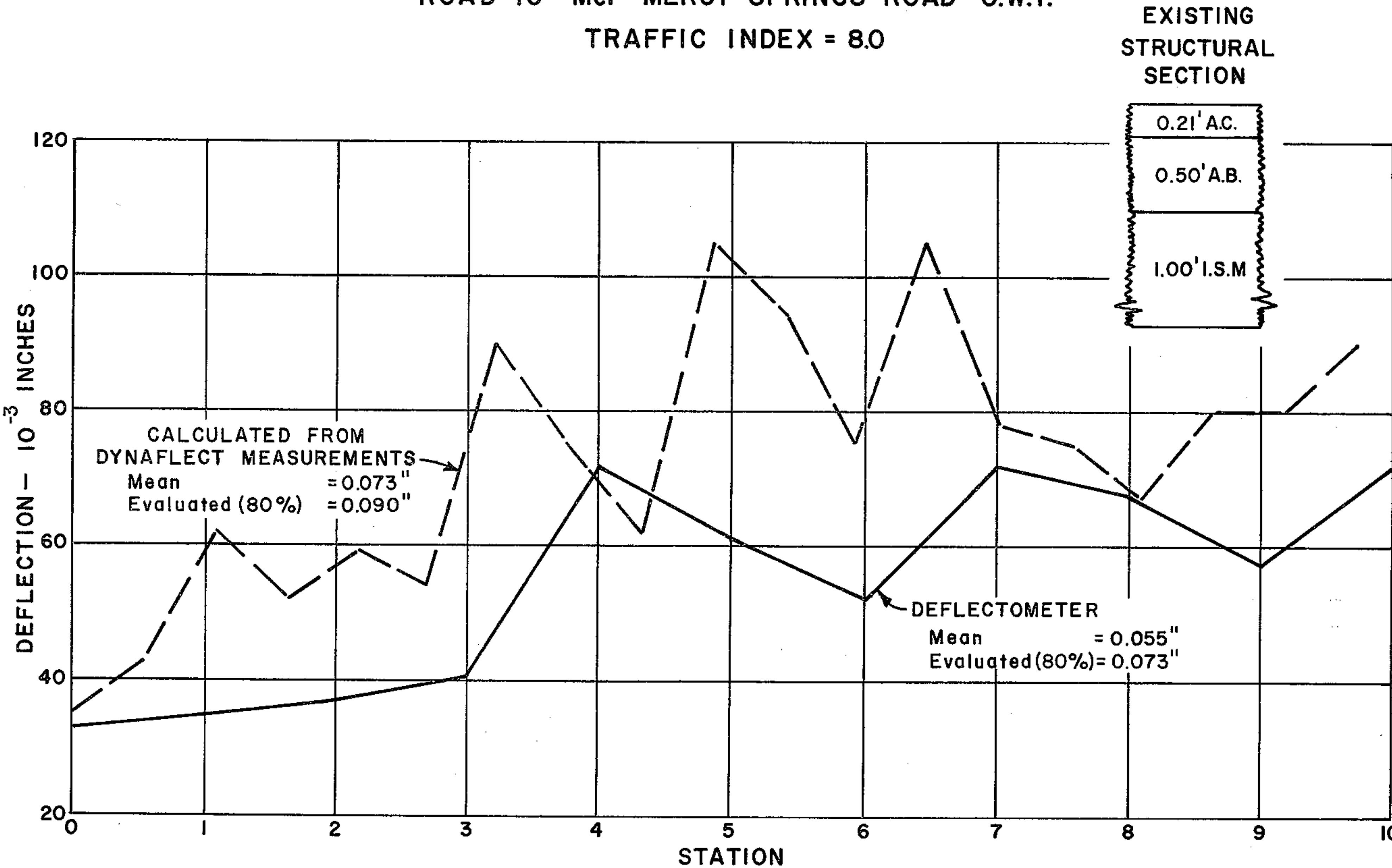



Figure 15

Figure 16

# VARIATION IN TOLERABLE DEFLECTION BASED ON A.C. FATIGUE TESTS

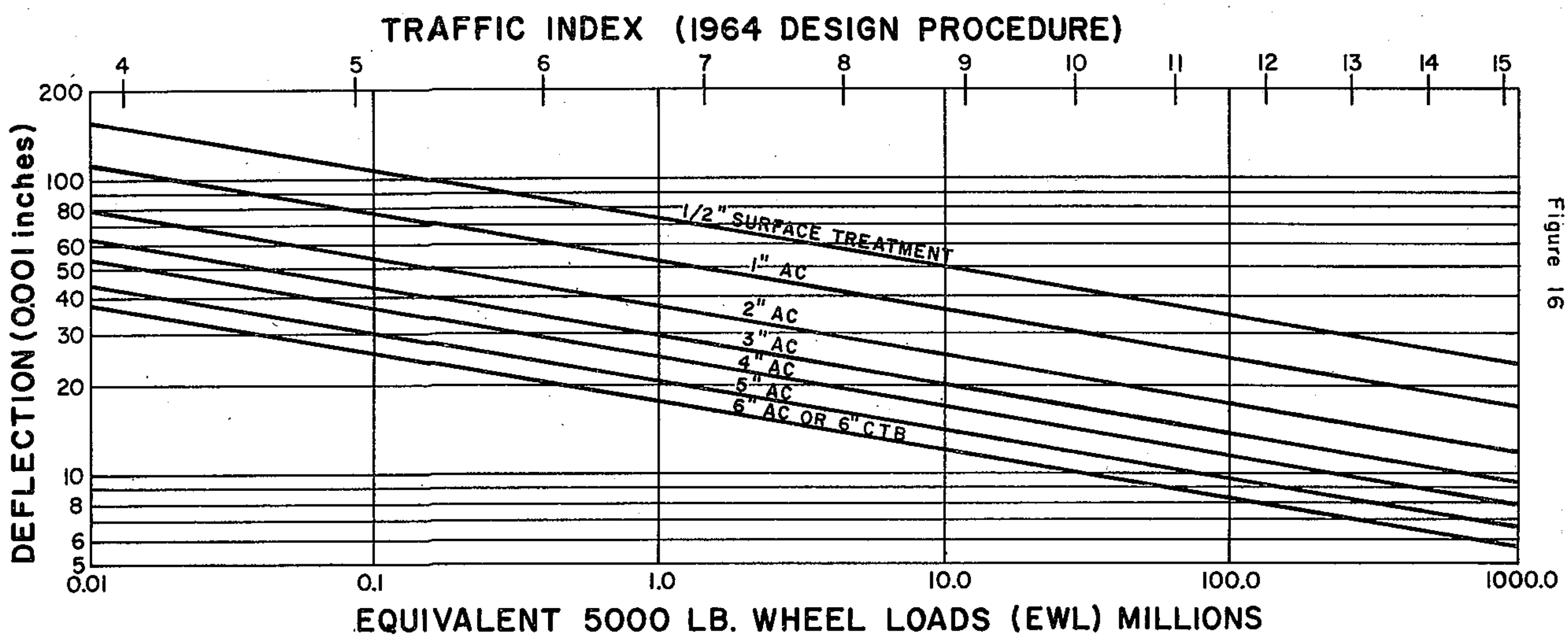


Figure 17

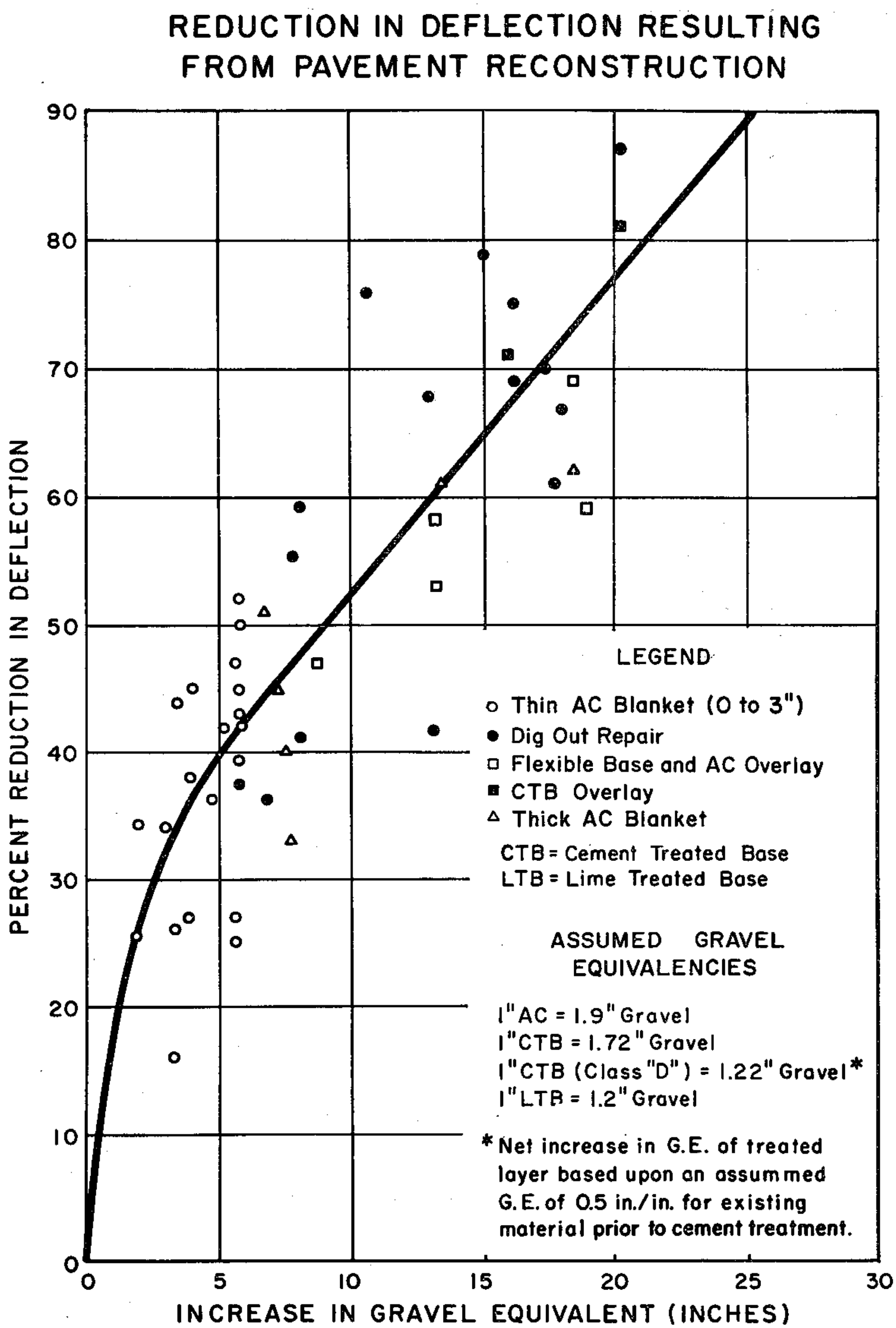
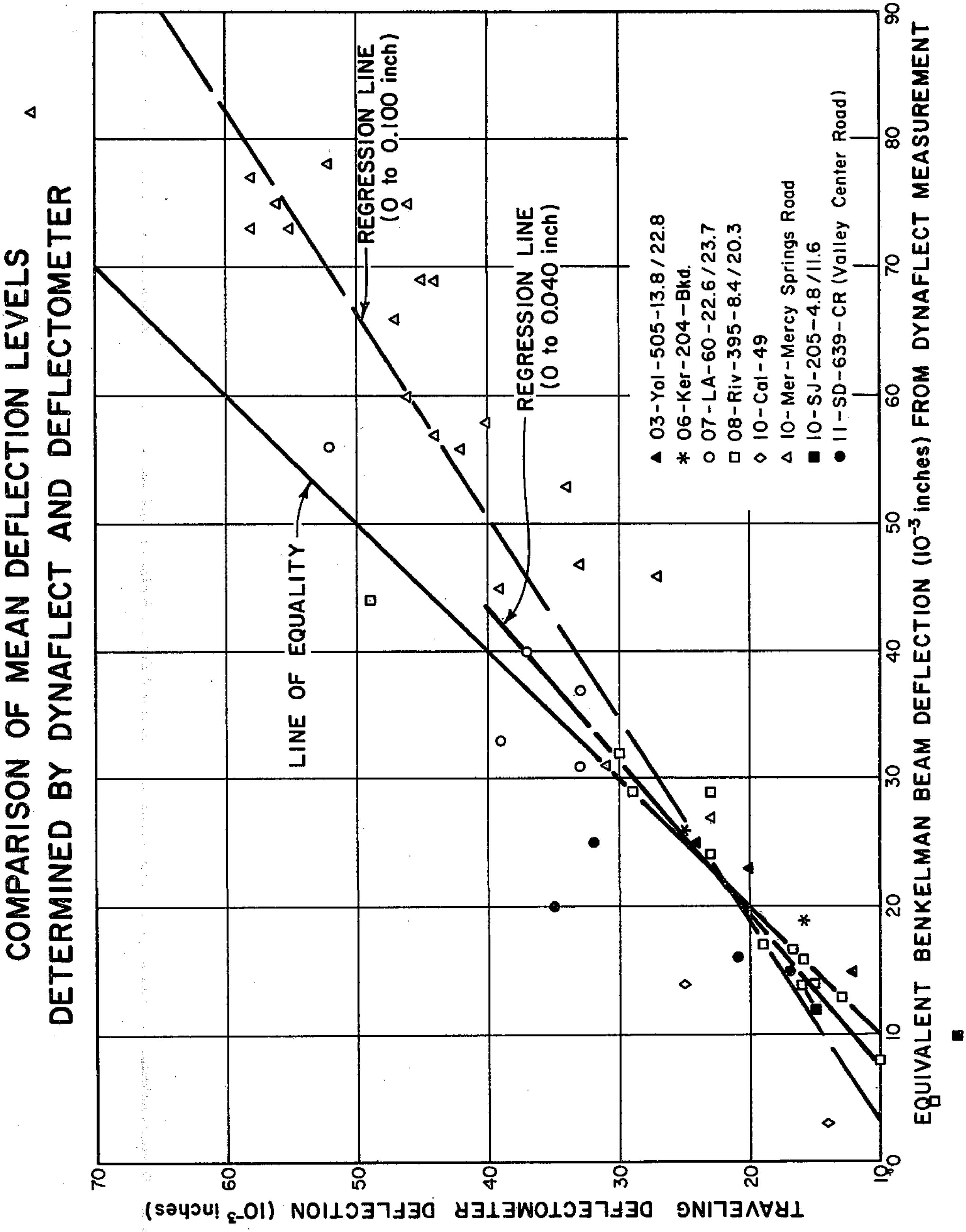

REDUCTION IN DEFLECTION RESULTING FROM PAVEMENT RECONSTRUCTION
PERCENT REDUCTION IN DEFLECTION
INCREASE IN GRAVEL EQUIVALENT (INCHES)
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
LEGEND
Thin AC Blanket (0 to 3")
Dig Out Repair
Flexible Base and AC Overlay
CTB Overlay
Thick AC Blanket
CTB = Cement Treated Base
LTB = Lime Treated Base
ASSUMED GRAVEL EQUIVALENCIES
1"AC = 1.9" Gravel
1"CTB = 1.72" Gravel
1"CTB (Class "D") = 1.22" Gravel*
1"LTB = 1.2" Gravel
*Net increase in G.E. of treated layer based upon an assummed G.E. of 0.5 in./in. for existing material prior to cement treatment.

Figure 18



COMPARISON OF MEAN DEFLECTION LEVELS
DETERMINED BY DYNAFLECT AND DEFLECTOMETER
REGRESSION LINE
(0 to 0.100 inch)
REGRESSION LINE
(0 to 0.040 inch)
LINE OF EQUALITY
03-Yol-505-13.8/22.8
06-Ker-204-Bkd.
07-LA-60-22.6/23.7
08-Riv-395-8.4/20.3
10-Cal-49
10-Mer-Mercy Springs Road
10-SJ-205-4.8/11.6
11-SD-639-CR (Valley Center Road)
EQUIVALENT BENKELMAN BEAM DEFLECTION ($10^{-3}$ inches) FROM DYNAFLECT MEASUREMENT
TRAVELING DEFLECTOMETER DEFLECTION ($10^{-3}$ inches)
0
10
20
30
40
50
60
70
80
90

# COMPARISON OF 80th PERCENTILE DEFLECTION LEVELS DETERMINED BY DYNAFLECT AND DEFLECTOMETER

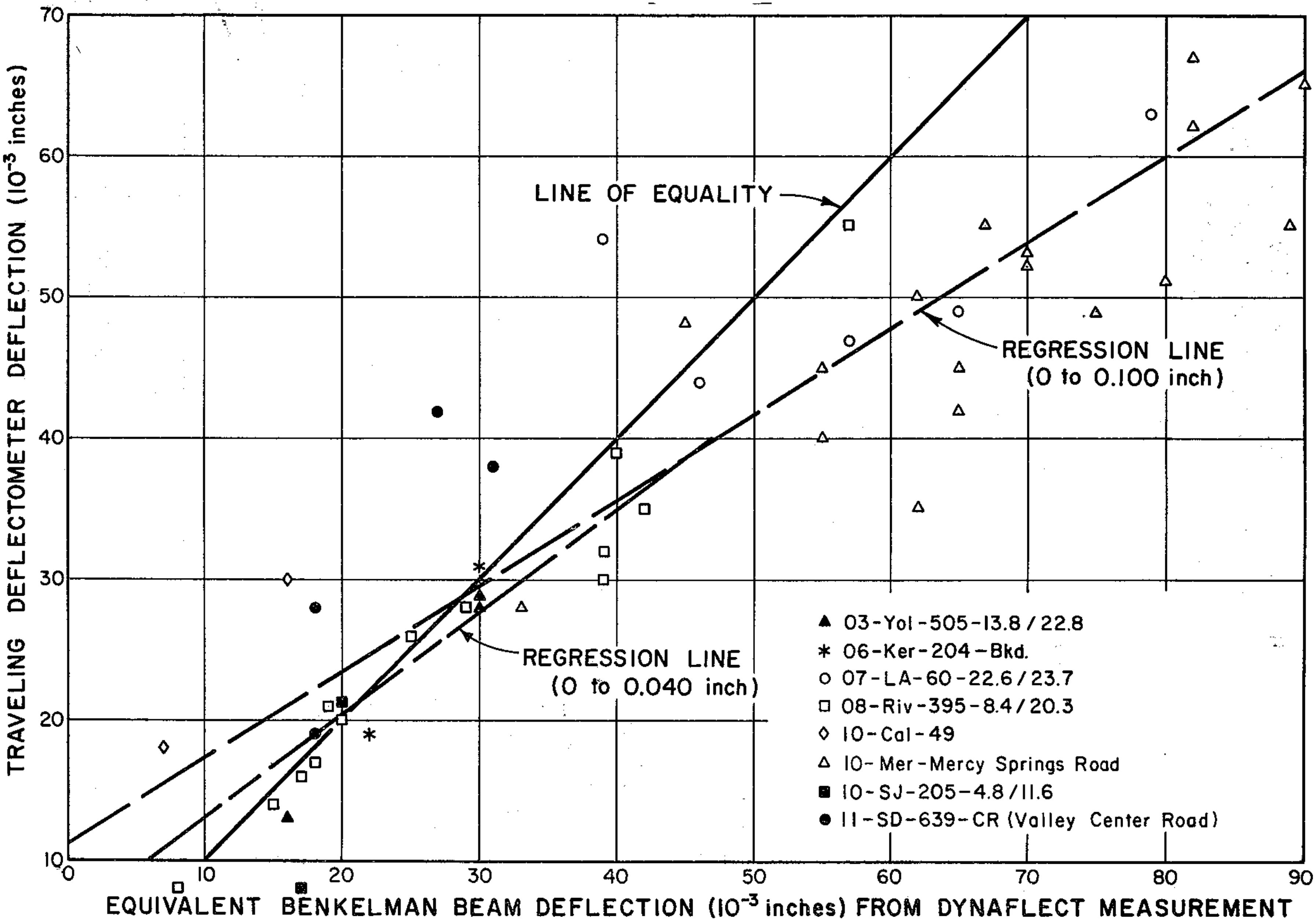


Figure 20

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON THREE (3) DIFFERENT STRUCTURAL SECTIONS

## 03 – Sac.-El Centro Road

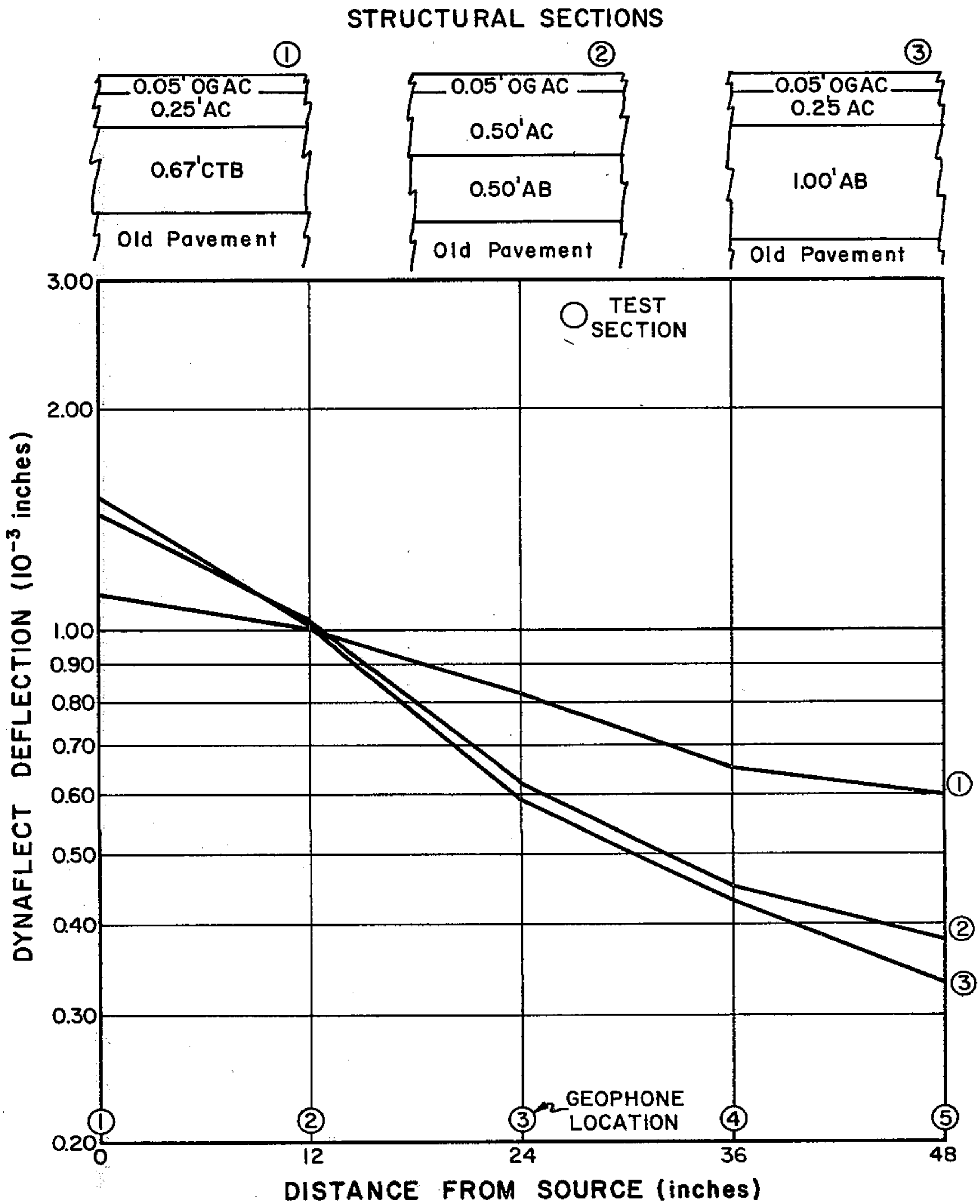


Figure 21

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON VARIOUS TEST SECTIONS
## 04 – C C – Ball Test Road

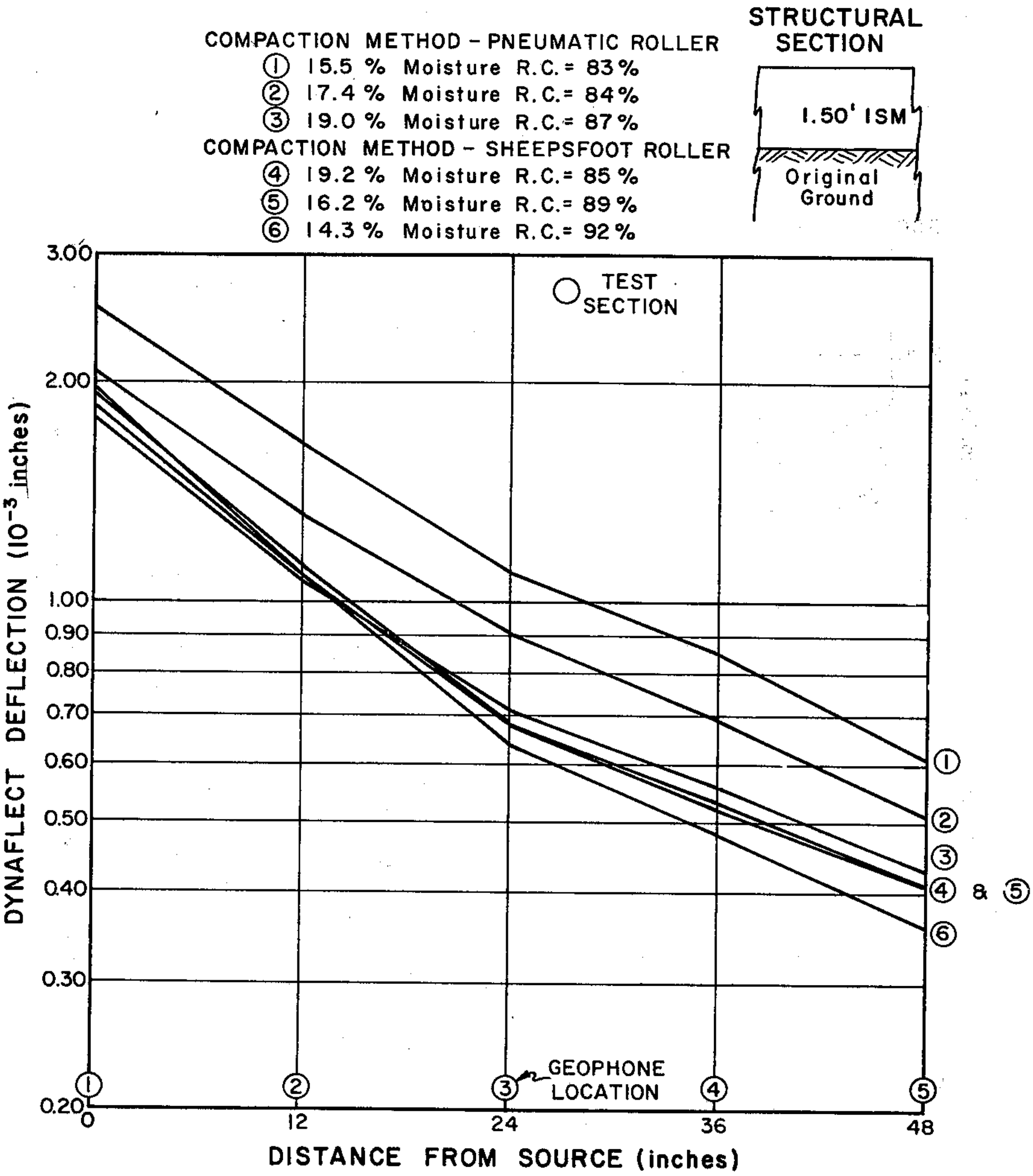
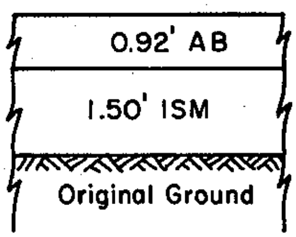


Figure 22

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON VARIOUS TEST SECTIONS

## 04 - CC - Ball Test Road

STRUCTURAL SECTION



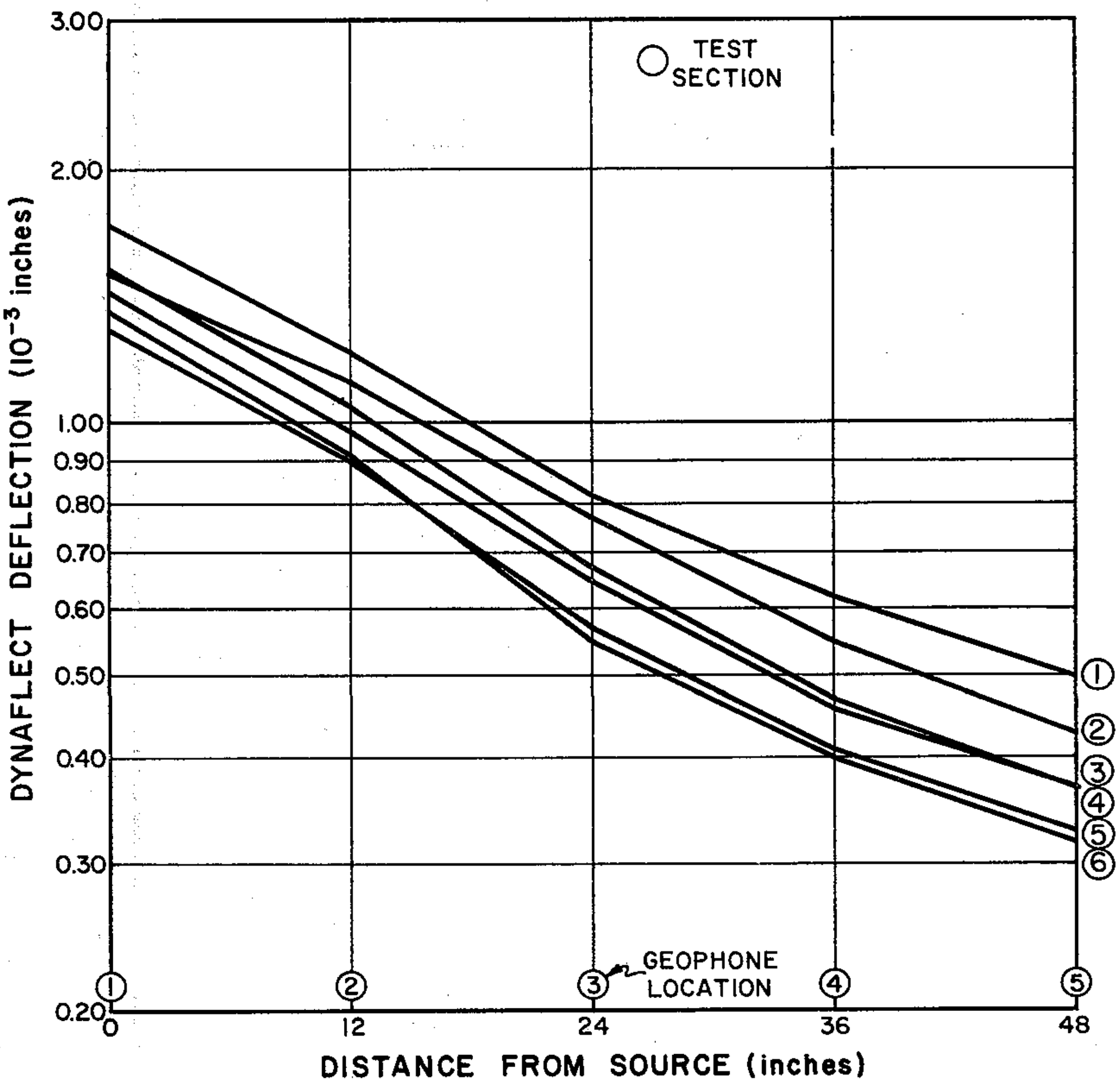



Figure 23

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON VARIOUS TEST SECTIONS
## 04 – C C – Ball Test Road

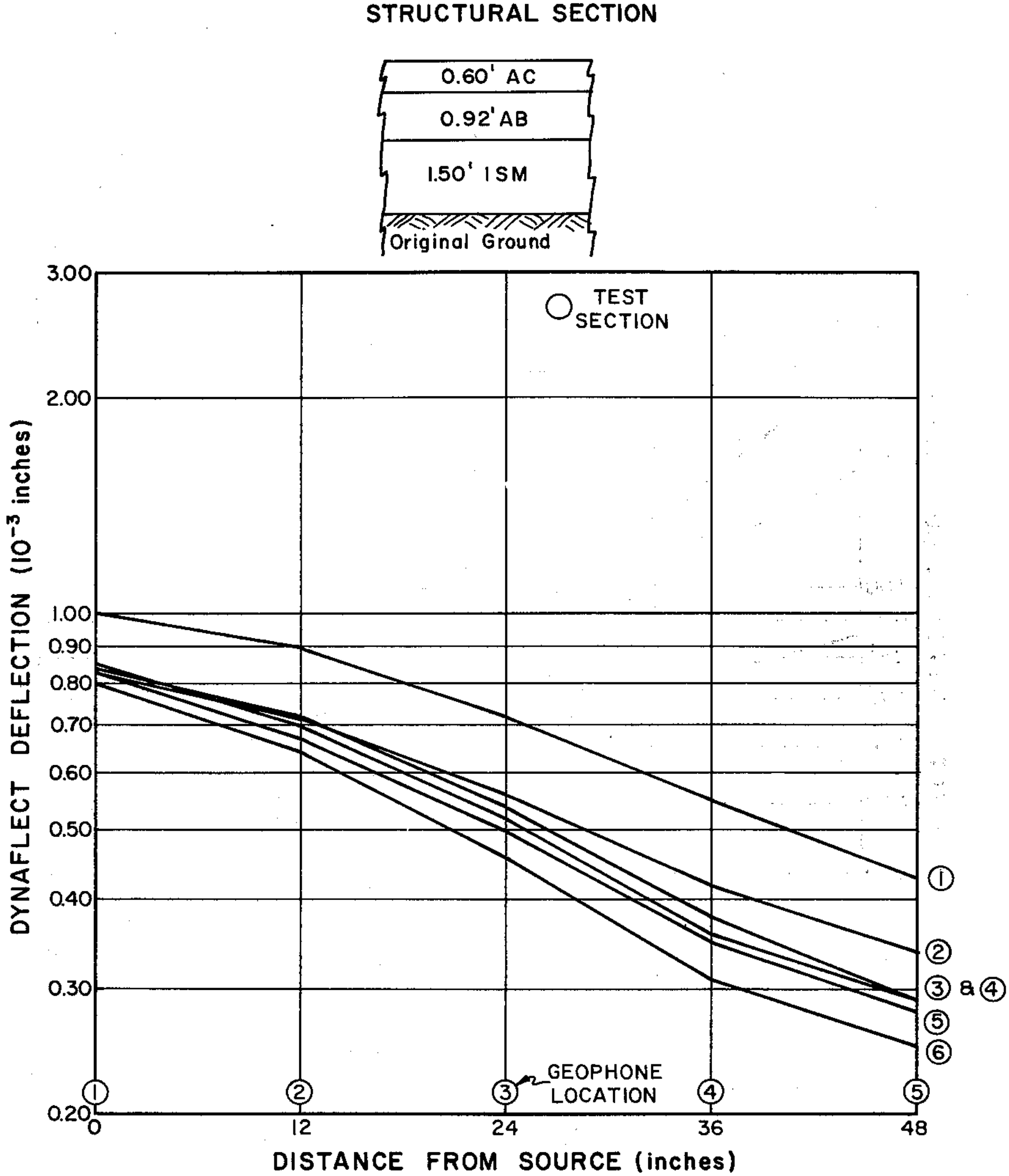


Figure 24

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON 04 - CC - Ball Test Road

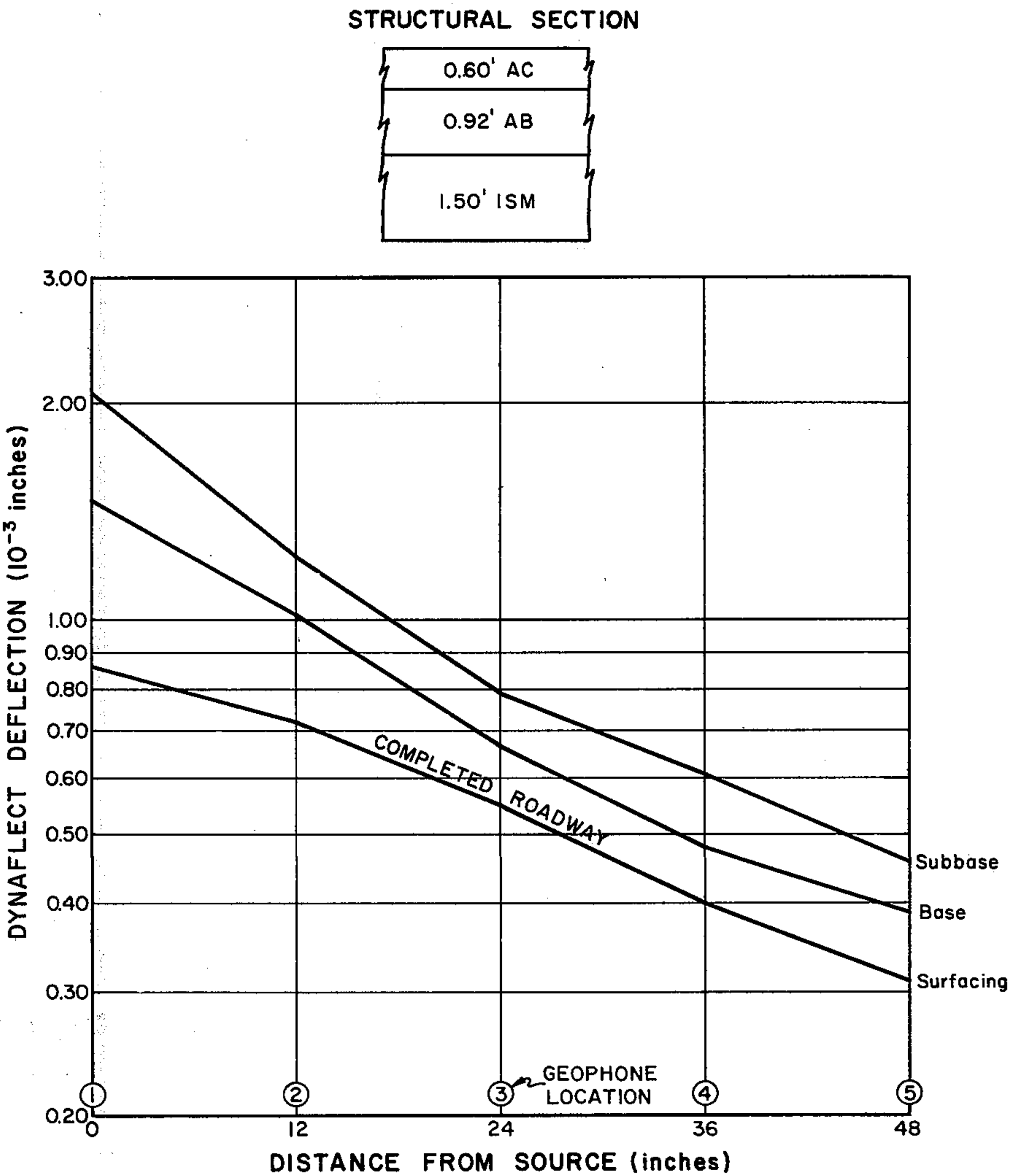


Figure 25

# MAXIMUM DEFLECTION VERSUS MAXIMUM SLOPE OF DEFLECTED PAVEMENT FROM DYNAFLECT READINGS

ASPHALT CONCRETE OVER CEMENT TREATED BASE

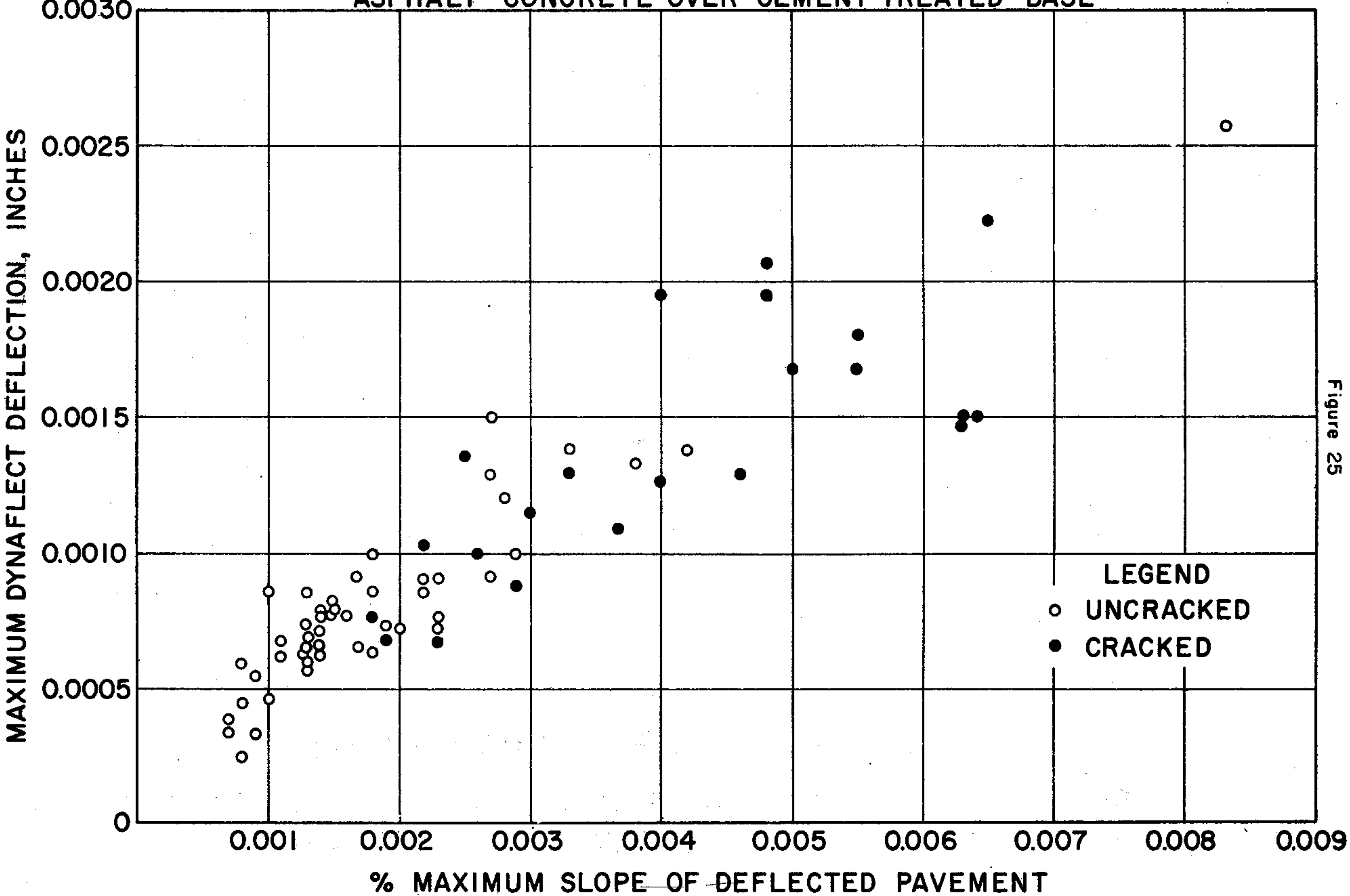


Figure 26

MAXIMUM DEFLECTION VERSUS MAXIMUM SLOPE OF DEFLECTED PAVEMENT FROM DYNAFLECT READINGS

**ASPHALT CONCRETE OVER FLEXIBLE BASE**

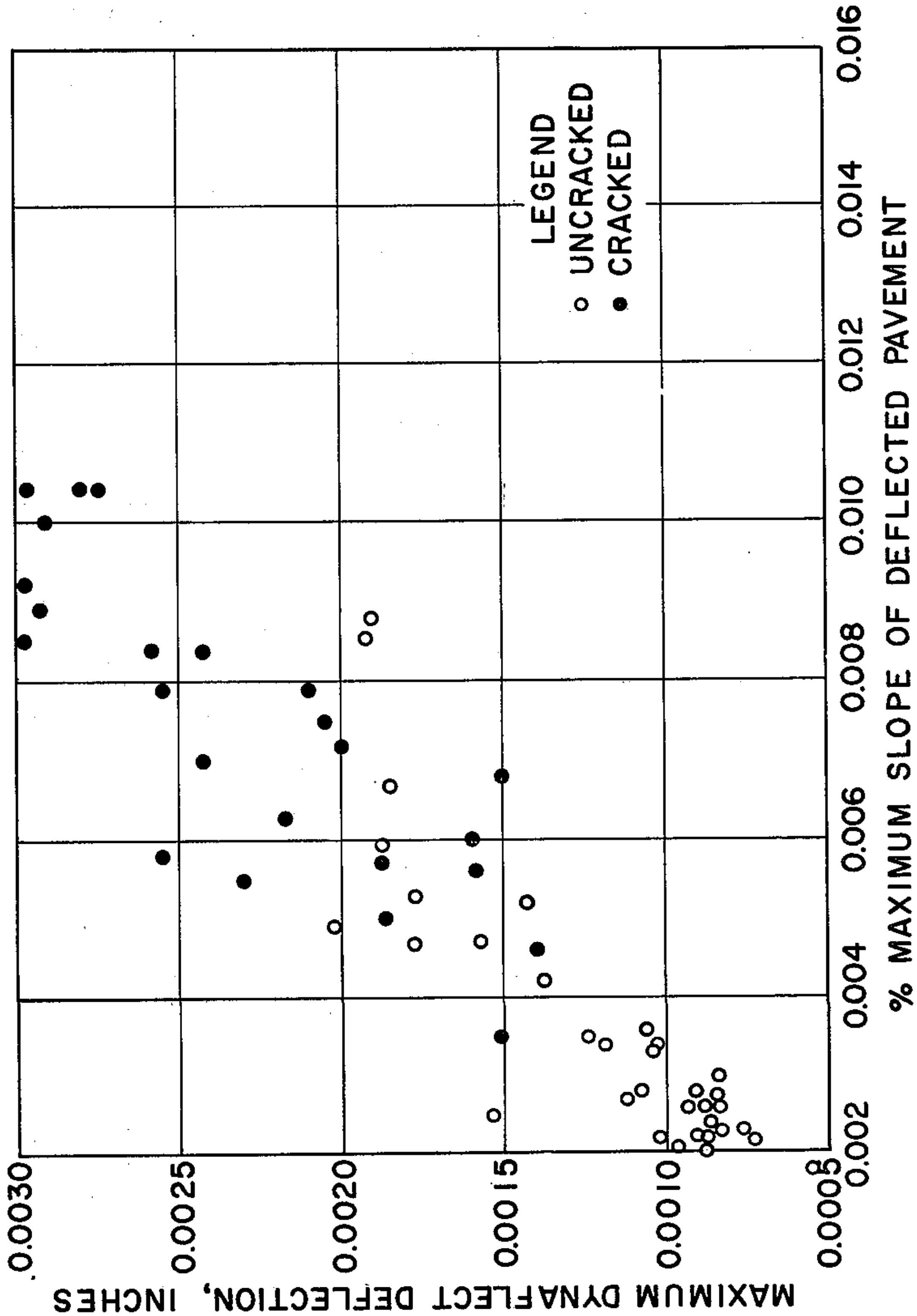


Figure 27

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON YGNACIO VALLEY ROAD CONTRA COSTA COUNTY

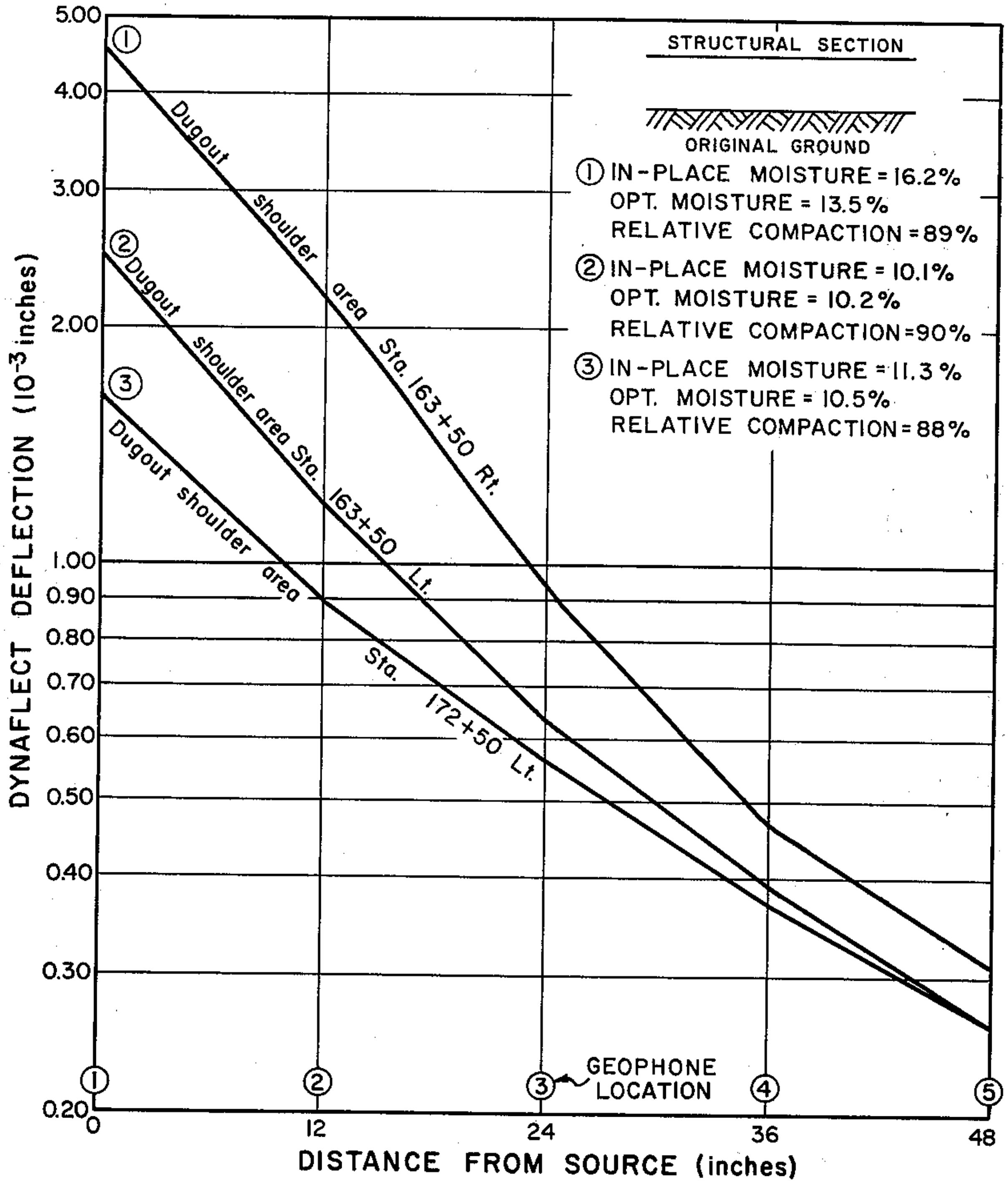
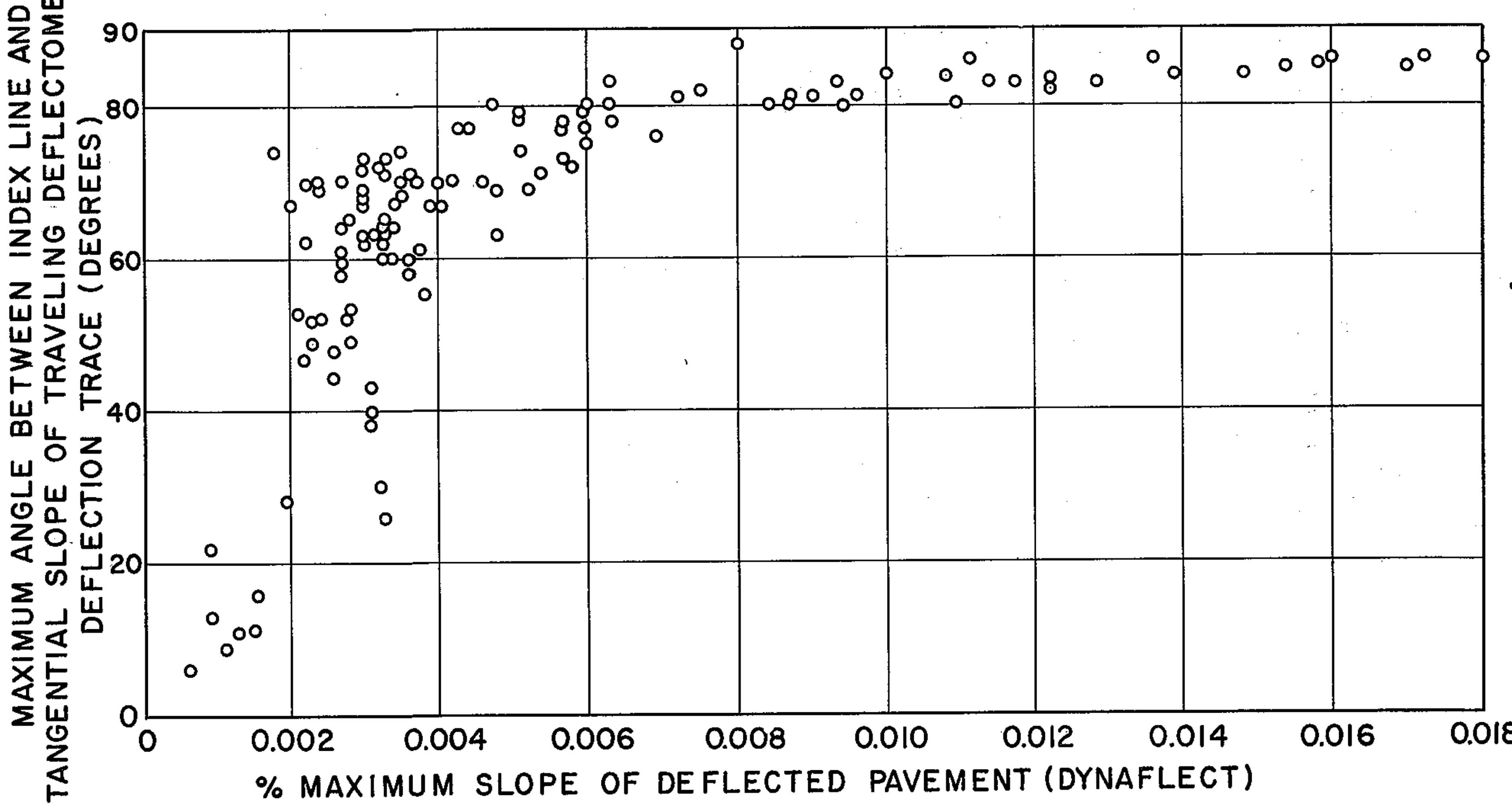


Figure 28

# COMPARISON OF DEFLECTED PAVEMENT BASINS DETERMINED BY DYNAFLECT AND TRAVELING DEFLECTOMETER



# COMPARISON OF INDICATED AND THEORETICAL DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ON 9 IN. PCC PAVEMENT

## 03 - Sac - 80

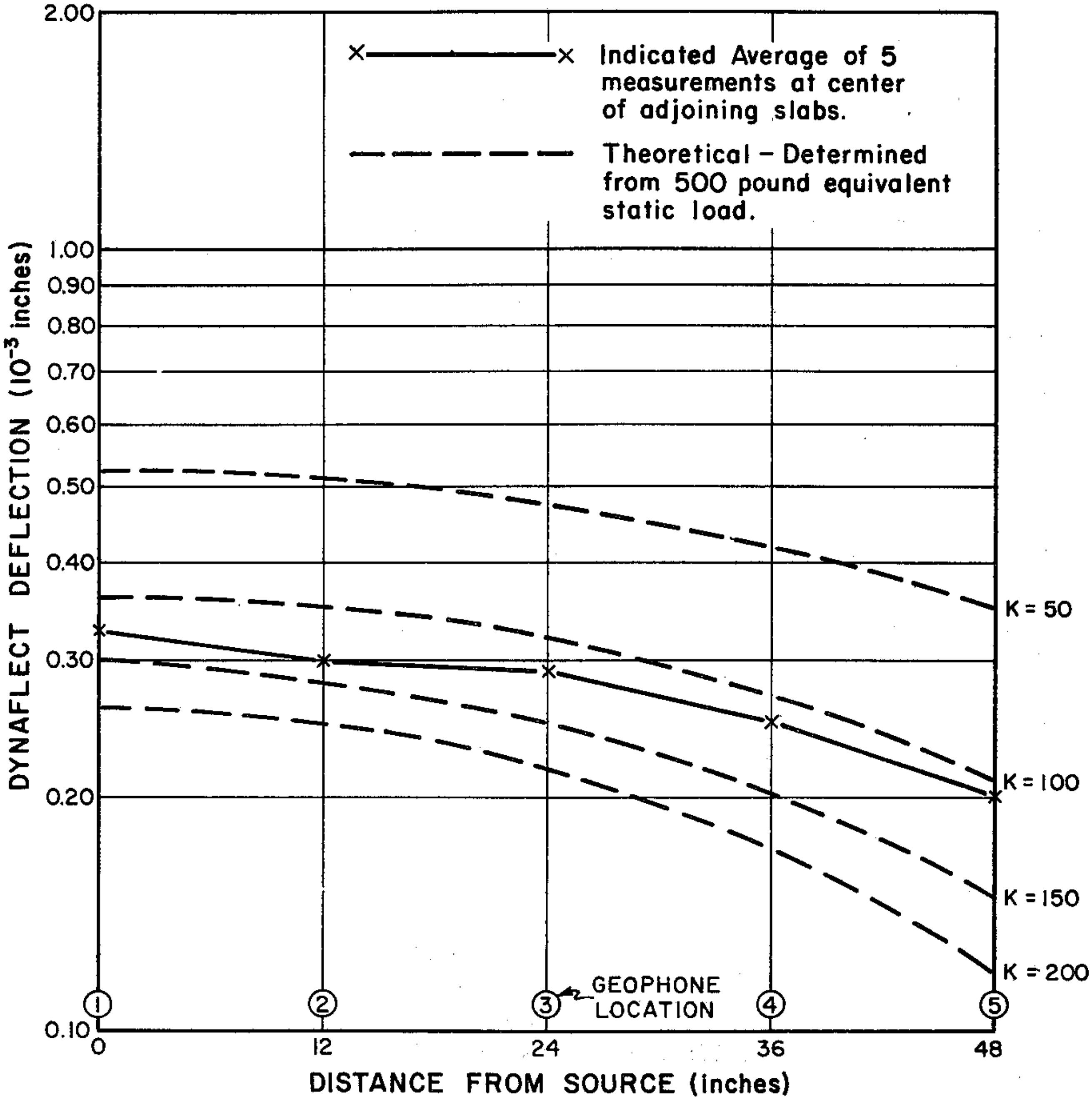
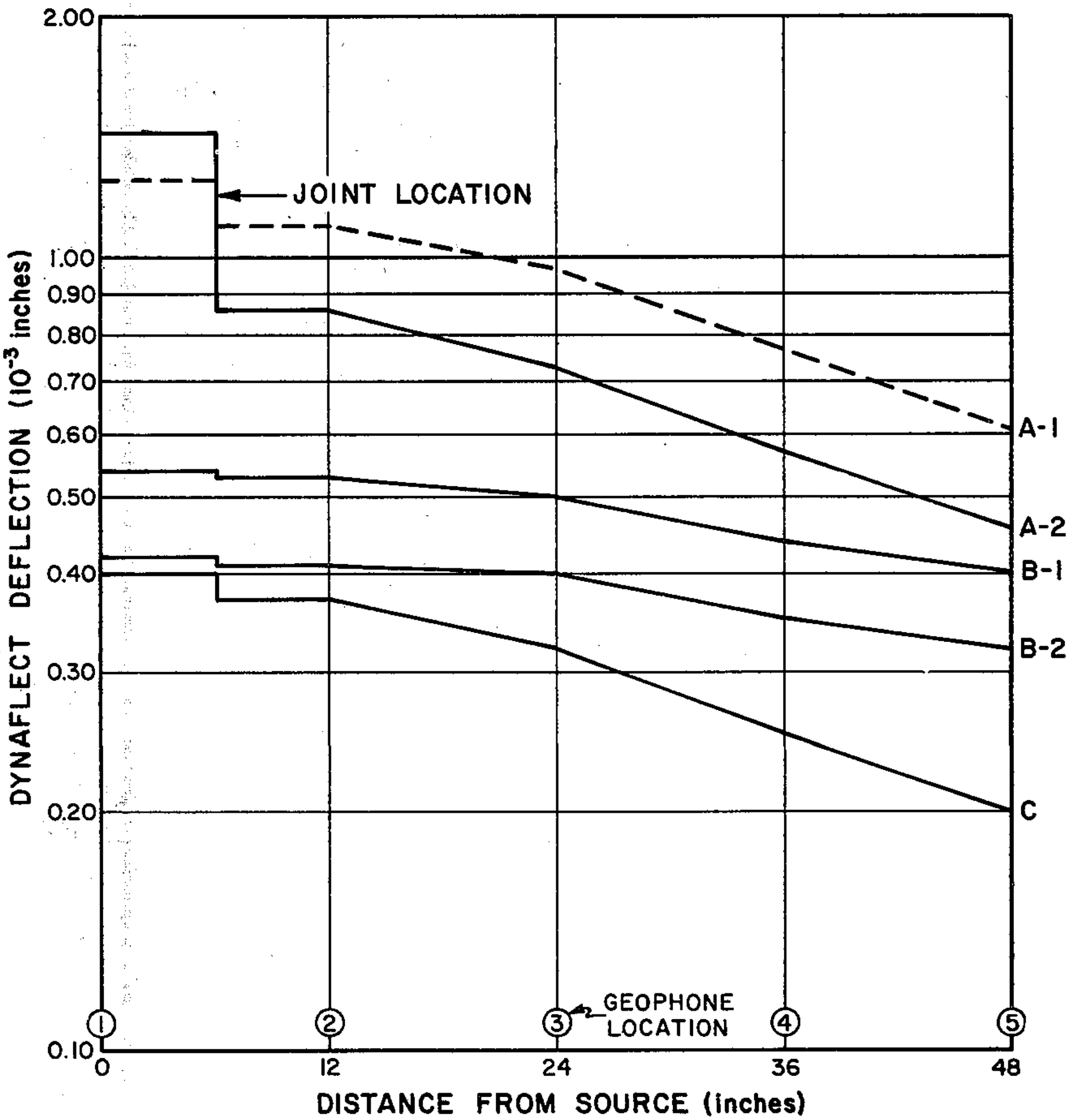


Figure 3.0

# DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ACROSS JOINTS OF ADJOINING PCC SLABS

A) 03 - Yol - 40 (not in service) 7" PCC (formed joints)
B) 03 - Sac - 5 9" PCC (sawed joints)
C) 03 - Sac - 80 9" PCC (sawed joints)



# COMPARISON OF DEFLECTED BASINS PRODUCED BY DYNAFLECT LOADING ACROSS JOINTS AND IN CENTER OF PCC SLABS

A) 03 - Yol - 40 (not in service) 7" PCC (formed joints)
B) 03 - Sac - 5 9" PCC (sawed joints)
C) 03 - Sac - 80 9" PCC (sawed joints)

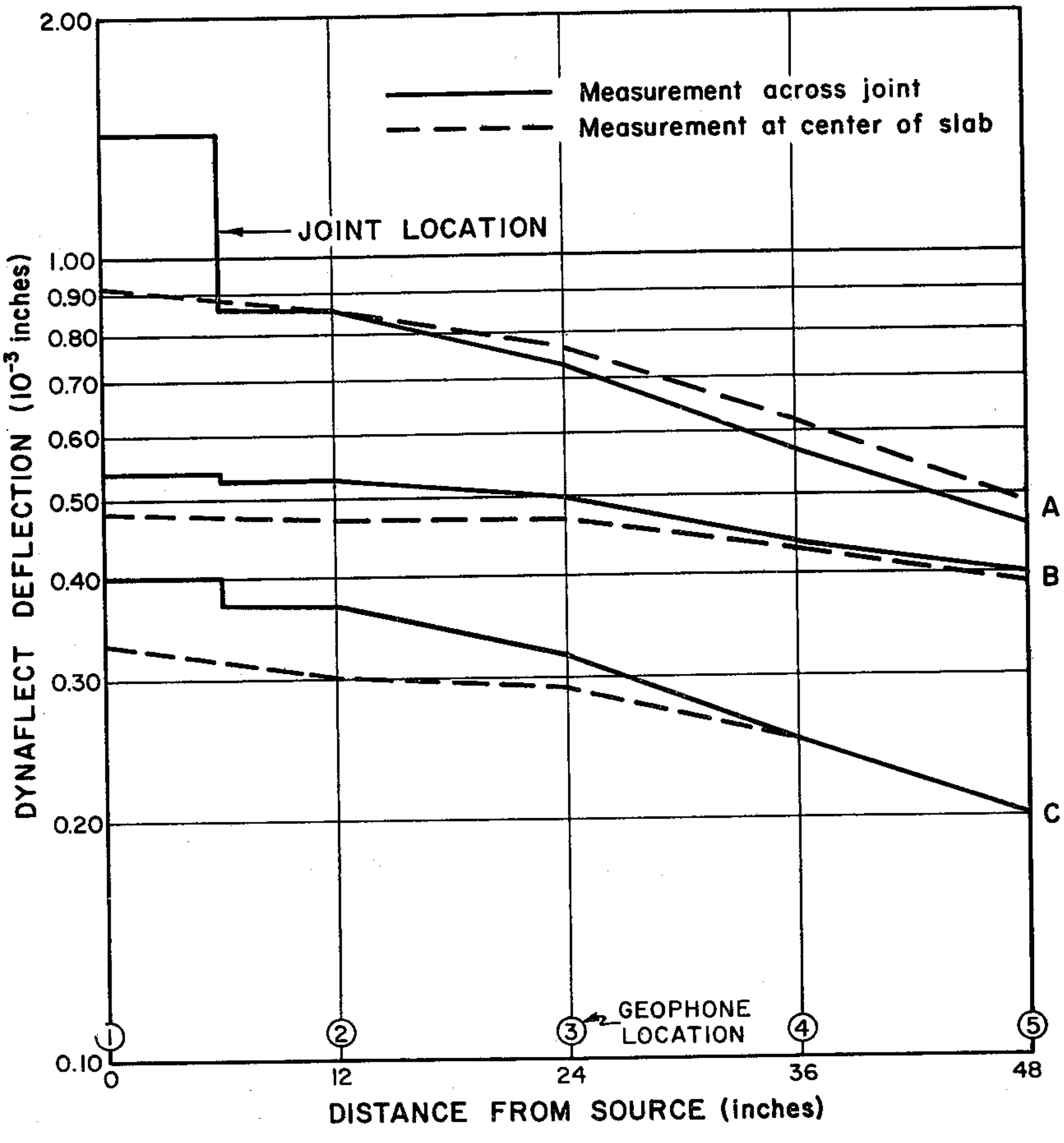


Figure 32

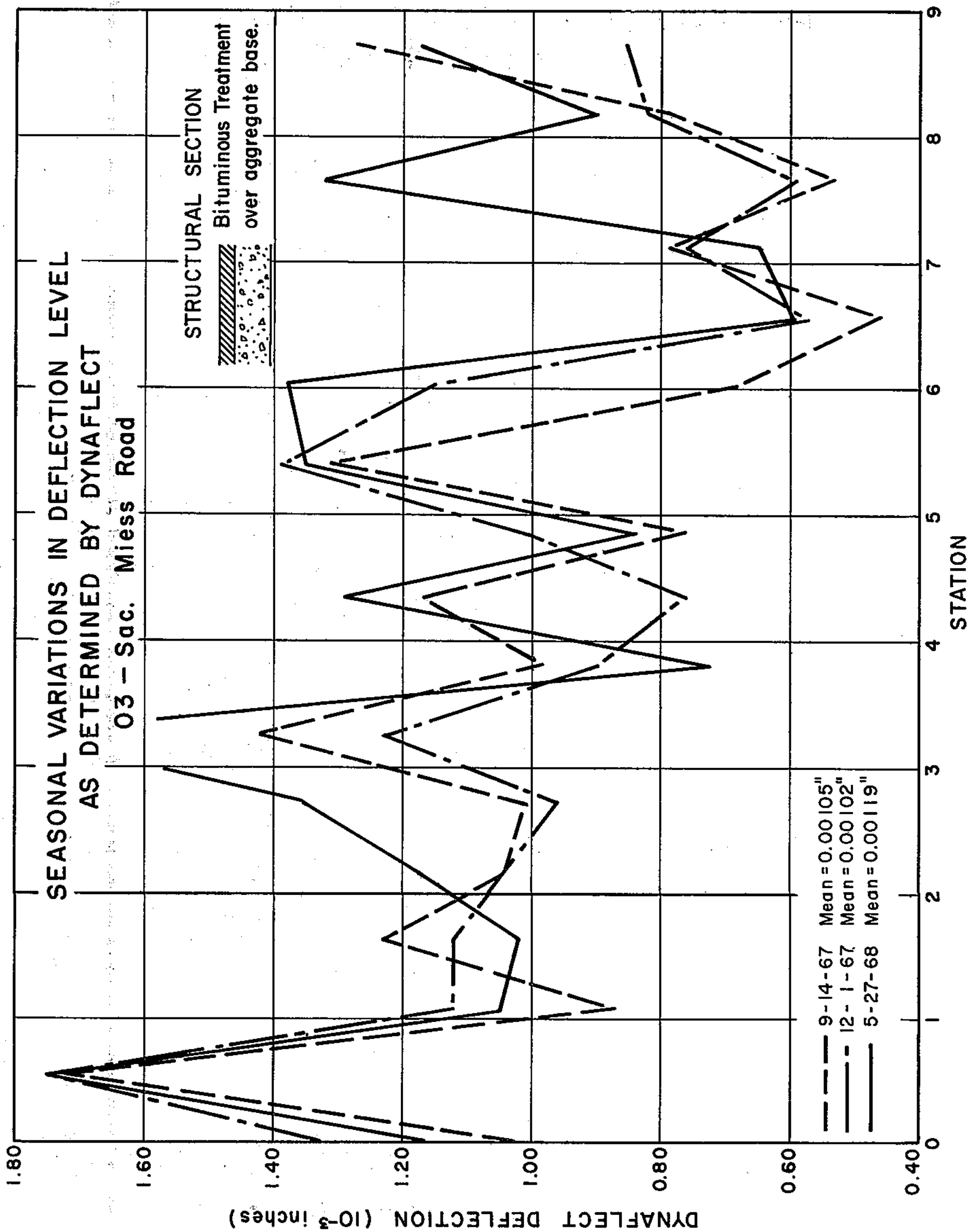

SEASONAL VARIATIONS IN DEFLECTION LEVEL
AS DETERMINED BY DYNAFLECT
03 – Sac. Miess Road
STRUCTURAL SECTION
Bituminous Treatment
over aggregate base.
9-14-67 Mean=0.00105"
12-1-67 Mean=0.00102"
5-27-68 Mean=0.00119"
STATION
0
1
2
3
4
5
6
7
8
9
DYNAFLECT DEFLECTION (10-3 inches)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40

Figure 33

# SEASONAL VARIATIONS IN DEFLECTION LEVEL AS DETERMINED BY DYNAFLECT

## 03 – Sac–Elverta Road

STRUCTURAL SECTION

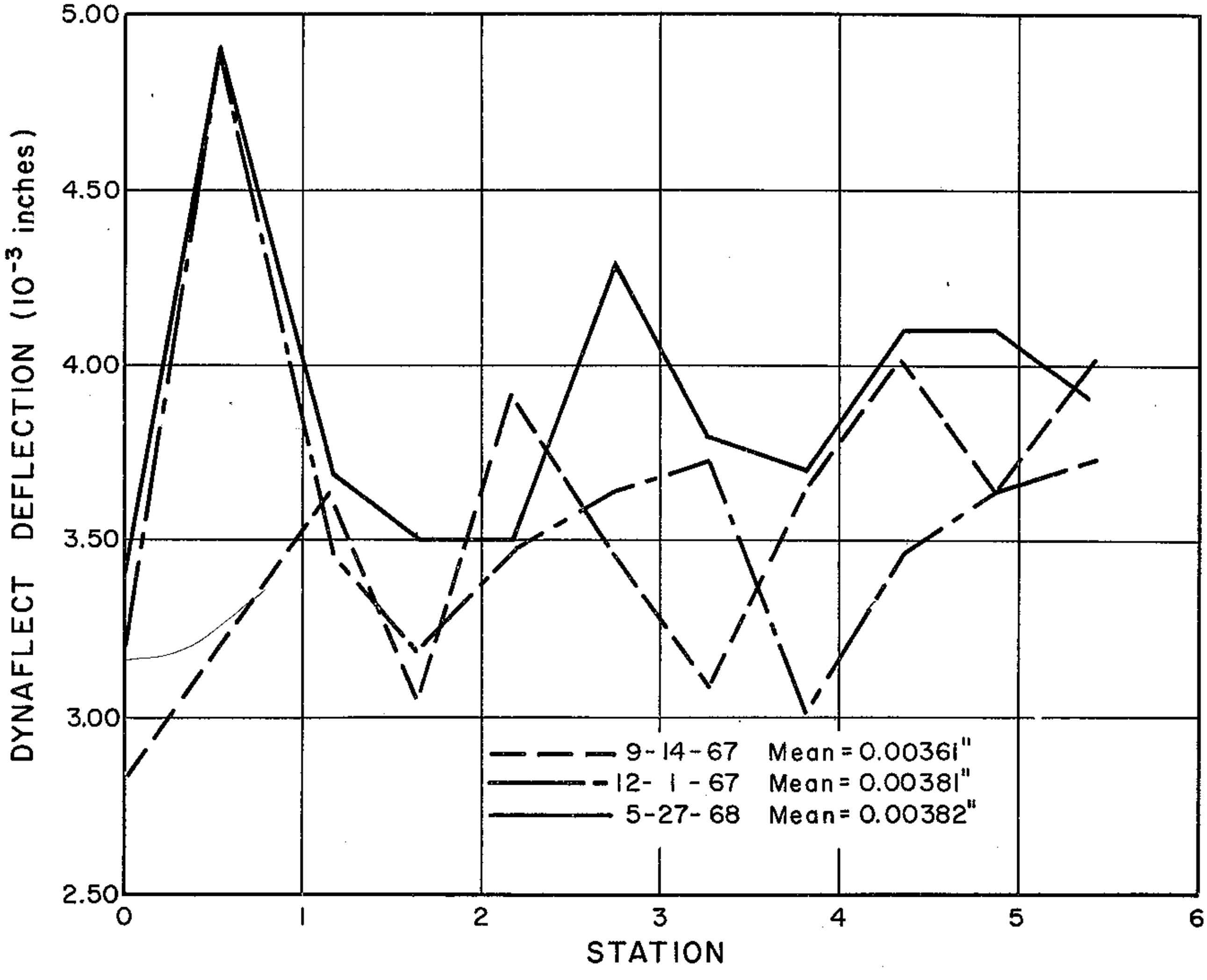



TABLE 1

Comparison of Traveling Deflectometer Deflection Levels to Those Obtained by Dynaflect Measurements

| Project | Equivalent Benkelman Beam Deflections Determined by the Dynaflect (Inches) | | Deflections Measured by the Traveling Deflectometer (Inches) | |
|---|---|---|---|---|
| | Mean | Evaluated 80 Percentile Level | Mean | Evaluated 80 Percentile Level |
| 03-Yol-505-13.8/22.8 | 0.023 | 0.030 | 0.020 | 0.028 |
| | 0.015 | 0.016 | 0.012 | 0.013 |
| | 0.025 | 0.030 | 0.024 | 0.028 |
| 06-Ker-204-Bkd. | 0.026 | 0.030 | 0.025 | 0.031 |
| | 0.019 | 0.022 | 0.016 | 0.019 |
| 07-LA-60-22.6/23.7 | 0.033 | 0.039 | 0.039 | 0.054 |
| | 0.037 | 0.057 | 0.033 | 0.047 |
| | 0.031 | 0.046 | 0.033 | 0.044 |
| | 0.056 | 0.079 | 0.052 | 0.063 |
| | 0.040 | 0.065 | 0.037 | 0.049 |
| 08-Riv-395-8.4/20.3 | 0.029 | 0.042 | 0.029 | 0.035 |
| | 0.044 | 0.057 | 0.049 | 0.055 |
| | 0.016 | 0.029 | 0.016 | 0.028 |
| | 0.008 | 0.015 | 0.010 | 0.014 |
| | 0.029 | 0.039 | 0.023 | 0.030 |
| | 0.017 | 0.025 | 0.019 | 0.026 |
| | 0.024 | 0.039 | 0.023 | 0.032 |
| | 0.016 | 0.020 | 0.016 | 0.020 |
| | 0.005 | 0.008 | 0.006 | 0.008 |
| | 0.013 | 0.017 | 0.013 | 0.016 |
| | 0.014 | 0.019 | 0.015 | 0.021 |
| | 0.014 | 0.018 | 0.016 | 0.017 |
| | 0.032 | 0.040 | 0.030 | 0.039 |
| 10-Cal-49-A | 0.014 | 0.016 | 0.025 | 0.030 |
| | 0.003 | 0.007 | 0.014 | 0.018 |

TABLE 1 (CON'T)

Comparison of Traveling Deflectometer Deflection Levels to Those Obtained by Dynaflect Measurements

| Project | Equivalent Benkelman Beam Deflections Determined by the Dynaflect (Inches) | | Deflections Measured by the Traveling Deflectometer (Inches) | |
|---|---|---|---|---|
| | Mean | Evaluated 80 Percentile Level | Mean | Evaluated 80 Percentile Level |
| 10-Mer-914(Mercy Springs Rd) | 0.027 | 0.033 | 0.023 | 0.028 |
| | 0.056 | 0.070 | 0.042 | 0.052 |
| | 0.073 | 0.082 | 0.058 | 0.067 |
| | 0.082 | 0.095 | 0.076 | 0.095 |
| | 0.069 | 0.075 | 0.044 | 0.049 |
| | 0.066 | 0.070 | 0.047 | 0.053 |
| | 0.058 | 0.065 | 0.040 | 0.045 |
| | 0.060 | 0.067 | 0.046 | 0.055 |
| | 0.031 | 0.045 | 0.031 | 0.048 |
| | 0.075 | 0.100 | 0.046 | 0.055 |
| | 0.078 | 0.089 | 0.052 | 0.055 |
| | 0.075 | 0.082 | 0.056 | 0.062 |
| | 0.077 | 0.090 | 0.058 | 0.065 |
| | 0.057 | 0.062 | 0.044 | 0.050 |
| | 0.073 | 0.090 | 0.055 | 0.073 |
| | 0.069 | 0.080 | 0.044 | 0.051 |
| | 0.053 | 0.065 | 0.034 | 0.042 |
| | 0.046 | 0.062 | 0.027 | 0.035 |
| | 0.047 | 0.055 | 0.033 | 0.040 |
| | 0.045 | 0.055 | 0.039 | 0.045 |
| 10-SJ-205-4.8/11.6 | 0.012 | 0.019 | 0.015 | 0.021 |
| | 0.010 | 0.017 | 0.004 | 0.008 |
| 11-SD-639-CR(Valley Center Rd) | 0.025 | 0.031 | 0.032 | 0.038 |
| | 0.016 | 0.018 | 0.021 | 0.028 |
| | 0.020 | 0.027 | 0.035 | 0.042 |
| | 0.015 | 0.018 | 0.017 | 0.019 |